THE UNIVERSITY OF ALBERTA

ELECTROMAGNETIC FIELDS OF ELEVATED DIPOLES ON A TWO-LAYER EARTH

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICS

Edmonton, Alberta

January, 1963

ABSTRACT

This thesis deals with the evaluation of the fields on the earth's surface of elevated, simply oriented dipoles. It contains a complete treatment of all four problems (vertical and horizontal electric and magnetic dipoles). Exact solutions for the Hertz vectors, some of which have not previously appeared in the literature, are derived. Approximations are applied and surface fields and impedances are calculated in the period range 0.1 - 10^4 seconds.

The complex integrals that appear in practically all field components have been evaluated with the aid of the IBM 1620 in the Computing Center, University of Alberta. The fields have been computed for a model earth composed of a highly conductive layer 4 km thick overlying a less conductive substratum extending downward to infinity. The behaviour of some of these fields have been carefully discussed.

Apparent resistivities of this earth model have been computed for the dipoles and compared with those based on Cagniard and the Price-Wait magneto-telluric theories. It is found that:

(1) The apparent resistivity (ρ_a) curves of the electric dipoles are very much different from those of the magnetic dipoles. Nor is there any resemblance between the

ρ_a curves of vertical and the horizontal electric dipoles.

(2) The Price-Wait ρ_a curves are very similar to those of magnetic dipoles. Thereby it is possible to understand better the meaning of the parameters (ν and λ) in their theories.

(3) Cagniard's theory is found to yield good approximations for apparent resistivities as compared with Price's and the dipole values in the short period (0.1 - 50 secs.) range. However, for longer periods (50 - 10,000 secs.) there is a considerable difference between Cagniard's value and that of the others. It is concluded by comparison with observation data that Cagniard's theory needs modification for the longer periods.

ACKNOWLEDGEMENTS

Upon the completion of this thesis, I wish to thank Dr. K. Vozoff sincerely for suggesting the problem and for his valuable discussions throughout the whole period of investigation.

I also wish to thank Dr. D. B. Scott, Director of the Computing Center, University of Alberta, for an assistantship in the Computing Center during the 1961-62 academic year, and also for an extremely generous allowance of computer time for the entire work.

This research has also been partly supported by an N.R.C. grant which I gratefully acknowledge.

I also thank Mr. R. M. Ellis for use of his program of Price's resistivity curves, and Mr. H. Hasegawa for his program of Cagniard's curves.

Last but not the least, I wish to thank Mrs. G. van Oene for her competent assistance in typing this thesis.

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I. INTRODUCTION

1.1 Statement of the Problem

The study of the electromagnetic fields of an oscillating dipole in free space is a fundamental but comparatively simple problem in classical electromagnetic theory. However, it becomes very difficult when one takes into account the disturbance caused by an electrically inhomogeneous spherical object like the earth. Basically, the investigation of the earth's disturbance on the dipole fields starts with the theory of earth wave propagation which arose about half a century ago with the invention of telegraphy. With the advent of modern radio technique in the last thirty years, the important practicality of the problem became all too obvious and consequently has been a subject of active and extensive investigation. However, as in many other practical problems, this has to be greatly idealized in order to make the calculation not too involved. As the work in this study shows later, even for an extremely simple model the mathematical complexity of the results renders impossible the immediate visualization of the field components without the help of a high speed computer.

In this study, the following simplifications will be made:

(1) The dimension of the dipole source is infinitely small in comparison with the wave length. The range of frequency we are interested in in this study is between 10^{-4} to 10 cycles per second ($T = .1 - 10^4$ sec.) with the corresponding wave lengths between $3 \times 10^7 - 3 \times 10^{12}$ meters in free space. When we take the ionic currents in the lower part of the ionosphere as a source, their dimensions should be small when compared to 3×10^7 meters for $T = .1$ sec. or 3×10^8 meters for $T = 1$ sec. Bomke (1962) has estimated that a magnetic dipole source for the geomagnetic fluctuation of 1 cps is about 400 - 500 meters in diameter, and comparatively larger for those of .1 - .01 cps. This criterion for small source dimension will therefore not likely invalidate our general results when applied to investigate these fluctuations.

(2) The earth is imagined to be a vertically inhomogeneous half space of two layers with plane boundaries. The top layer is of uniform finite thickness in contrast to the substratum which extends to infinity. The flatness of the earth is justified if the height of the dipole is not too great and the observation distance not too large in comparison with the earth's radius; here , only the results calculated from low frequencies will be discussed. While three or more layered models will present no more difficulty in principle, the calculation resulting from these models will certainly be a great deal more involved because of the additional boundaries one has to consider.

(3) The upper half space in which the dipoles are situated is considered to be free space, i.e. the conductivity of the air is considered negligible and the permitivity and permeability equal to ϵ_0 and μ_0 respectively. In other words, the refractive index of the earth is much greater than unity.

(4) Ionospheric influence is neglected in the development. Strictly speaking, if the dipole is situated in the space between the earth and the ionosphere, the influence of the latter is significant for higher frequencies, although for short ranges of distance the ground wave may dominate the ionsopheric reflected waves and the neglect of the ionospheric influence is therefore permissible. In this study, the source itself is taken as a component of the ionospheric disturbance, therefore no reflected waves from the ionosphere need be considered.

1.2 Historical Review

To put the problem in its proper historical perspective, one should really begin with the investigation of electromagnetic wave propagation in presence of a spherical object near the end of the last century, when physicists did rigorous research on the scattering of light in the atmosphere, on optical phenomena caused by colloidal particles, and on the distribution of light in a rainbow and other related topics. In all these problems the particles are good reflectors and light sources are placed at infinite distance from them. In the case of a radiating dipole in presence of the earth, the distance

between the source and the object is finite and the earth is not a good reflector in the frequency range of interest here. Despite the differences in their physical constants and geometric configurations, all these problems can be generalized into a diffraction problem. Naturally, these differences yield completely different results in each case. However, it is precisely the difference from all the other problems cited above that enables one to make a simple-minded approach toward a final solution for the problem under consideration as developed by A. Sommerfeld.

Sommerfeld established the classic approach to solving this problem in two papers published in 1909 and 1926. He treated the earth as a homogeneous half space with a flat boundary. The dipole was situated above the surface of the earth. By argument of symmetry, he obtained Hertzian vectors in an integral form and expressed the electric and magnetic fields as derivatives of these Hertzian vectors. The entire problem is a boundary value problem. Since his method will be set forth in Chapter 2 of this thesis, it is not necessary to dwell upon it here in greater detail. However it is important to note that many papers published in the following thirty years were based upon his work.

Following Sommerfeld, B. Van der Pol (1935) developed the theory of reflection of electromagnetic waves from a dipole by a conducting flat earth by analogy to the theory of the reflection of light from a mirror. He extended the mathematical results given by Sommerfeld and gave them a physical

interpretation. He concluded that in the first medium (air) the fields can be described as the result of the secondary waves originating in the second (conducting) space in addition to the direct radiation from the source. The amplitude of these secondary waves is determined by the amplitude of a primary wave which can be considered to spread from the geometrical image of the point source with the propagation constant and absorption coefficient of the second medium. The higher the conductivity of this second medium, the more the primary wave is concentrated near the image of the point source. As a limit when the second medium has an infinite conductivity, the primary wave is wholly concentrated at the image itself.

Van der Pol and Bremmer (1937, 1938) developed a rigorous theory of the diffraction of electromagnetic wave from a point source around a spherical object, and applied this to the theory of the rainbow and radio wave propagation around the earth. In 1938 they specifically extended the theory for radio waves over a finitely conducting earth. In the 1937 paper they gave explicit formulae for two limiting cases, namely total reflection and maximum absorption while in 1938 they derived approximate expressions for the most general case for all intermediate values of σ (conductivity) and ϵ (permitivity) and for all frequencies. In both papers, they let the radius of the sphere approach infinity and in the limit they obtained expressions formerly given by Sommerfeld for a flat earth.

While Van der Pol and Bremmer's approach is valued

for its generality because it includes the effect of the earth's curvature, Sommerfeld's treatment has the advantage of simplicity and straightforwardness. It is not difficult to see when the earth is vertically inhomogeneous, Van der Pol and Bremmer's treatment will be much more complicated than Sommerfeld's and consequently Sommerfeld's is preferred. Strictly speaking, for near fields and certain frequency ranges, the neglect of the earth's curvature results in no loss of generality. To conclude this classic phase of the development, it should also be mentioned that besides Sommerfeld, Van der Pol and Bremmer, Weyl, Niessen, Lord Rayleigh and Mie also had made valuable contribution to the problem.

Late in the 1920's and throughout the 1930's the radio engineers had done a great deal of work in connection with the properties of the dipole radiation fields on the surface of a homogeneous ground. Norton (1937) gave a very complete analysis of the dipole fields on a flat homogeneous earth. The engineer's calculations were exclusively based on the previous works of Sommerfeld, Van der Pol and Niessen. In the meantime the telephone engineers simulated a horizontal electric dipole with a short wire and integrated Sommerfeld's results for a horizontal electric dipole to obtain the fields of infinitely long wires, calculating the mutual impedance between two such wires. It is worth noting that many of the later publications made use of these results (Wait, 1951, Wolf, 1946).

In spite of the fact that electrical prospecting had claimed considerable amount of success in the early 30's, de-

tailed study of dipole fields as a tool of geophysical prospecting had not been carried out until much later. A. Wolf (1946) seems to be the first writer to develop rigorous mathematical expressions for prospecting purposes. In his paper the source is a horizontal electric dipole lying on the surface of a two layer ground. The earth is treated as flat and no influence of the ionosphere is included. The method he has used is the method developed by Sommerfeld as mentioned earlier. However, due to the formidable complexity of the integrals involved, in order to give any useful results he has to resort to drastic approximations. Consequently, he has determined only the electric fields of two special cases, namely the case in which the conductivities of the two layers are nearly equal and the case in which the lower layer is a perfect insulator. In the former case he retains only the first order terms in $\Delta\sigma$ ($= \sigma_2 - \sigma_1$, the conductivity contrast) and in the latter case only terms of zero and first order in frequency are considered. In both cases he illustrates the use of these expressions by calculating the mutual impedance between two short wires, one being the dipole source.

In 1951 two major papers on dipole fields were published in connection with geophysical exploration problems. They are by Slichter and Wait.

Slichter (1951) has discussed an interpretation problem of electromagnetic prospecting. He uses an arbitrary circular current sheet perpendicular to a flat, two layer ground as a magnetic dipole source. He assumes the electromag-

netic properties of the substratum as constant but those in the top layer are unknown functions of depth. By subjecting the earth to a dipole field, he has derived expressions of these unknown functions of depth by inverse Fourier transform. The final results are in terms of continuous measurements of the radial and vertical magnetic fields on the surface of the ground, theoretically out to infinite distance. Since he also shows that under this situation the horizontal and vertical magnetic fields are mutually dependent, it is necessary to measure only one component of the magnetic field on the surface of the earth. While he has not provided any expression for the electromagnetic fields of a dipole above a conducting earth, his approach is nevertheless fresh and stimulating.

Wait (1951) has derived formal solutions for a magnetic dipole on the surface of a two-layered earth, mainly following Sommerfeld. The energy source is harmonic in time and is simulated by a current loop. In this paper he has derived expressions for mutual impedance between two coplanar loops (horizontal on the ground) and between a loop and a segment of wire lying on the ground. As subject to mathematical difficulties, he can only treat some special cases: the case of a homogeneous flat earth, the case of a poorly conducting upper layer, and the case of a thin conducting sheet of infinite horizontal extent upon a substratum of poor conductivity. He did, however, give great mathematical details for each case and some of the results in terms of tabulated integrals (Foster, 1933).

Between the years 1951 and 1962, Wait has published no less than 25 notes and papers on the topic of dipole radiation fields over a flat earth. Nearly all of them invariably follow the approach developed by Sommerfeld. Most of them are extensions of the mutual coupling of loops and wires on the surface of the earth. All are developed for the purpose of geophysical prospecting.

Slichter and Knopoff (1959) have extended the results of one of the authors (Slichter 1951) through a high speed computer for a vertical magnetic dipole on the surface of a 2-layered earth. However, for mathematical convenience, they have adopted for dipole source a rather artificial circular current sheet with a current density $C = [c](\rho/\rho_0)e^{-i\omega t}$, where $\rho < \rho_0$, ρ being the radial distance from the centre and ρ_0 the radius of the source, and [c] being the unit of current density. Extensive values of the field components have been calculated for different values of dimensionless conductivity and at various numerical distances from the source. Since the parameters used are dimensionless, the computed values and curves can be used for many different layer thickness and conductivities. However, since they are aiming at a solution for geophysical exploration purposes, they have only given in- and out-of-phase magnitude of the magnetic fields.

Owing to the fact that the dipole field study is one of great interest to both the communication engineers and the exploration geophysicist and that publications in its

connection covers a vast area, it is almost impossible to scrutinize all the papers on the topic. Nevertheless, great care has been taken in this section to cover what is considered to be of prime interest to this study.

1.3 Connection with Other Problems

As reviewed in the last section, the study of the dipole fields in presence of the earth is interesting in its own right, and it is even more so for its very useful application in exploration geophysics and communication engineering. However, its possible connection with natural geophysical phenomena also offers a great opportunity for serious investigation. This section is therefore devoted to the consideration of two related problems that may gain some clarification from this study.

The magnetic dipole found its way into geophysics in a rather grand manner when William Gilbert published De Magnete in 1600. By then it was known that a magnetized needle not only tended to point north but if free to move vertically would also dip in the northern hemisphere and tilt upward in the southern hemisphere. Seeking an explanation for this behaviour, Gilbert boldly assumed the earth as a giant magnet and the earth's magnetic field as a dipole field. The next three and one half centuries have witnessed drastic modifications of Gilbert's assumption that the earth is a permanent magnet. During this period the earth's magnetic field

has been analysed with great mathematical elegance. However, the main field is still recognized as a dipole field arising in the earth's interior. Superposed on the main field are many types of rapid geomagnetic variations which, to a greater or lesser extent, are due to the changing physical conditions in the upper atmosphere. A typical example of these is the magnetic storm for which the sudden disruption of the upper part of the ionosphere by solar particles bears the responsibility.

Among these geomagnetic variations is one type which is now widely known as geomagnetic micropulsations. These pulsations are now recognized to originate outside the earth. Geophysicists are now diligently studying these pulsations and making good attempt to use them to investigate the interior of the earth. This kind of investigation is based upon a theory generalized by Cagniard (1953) which is now known as the magnetotelluric theory. Both the geomagnetic micropulsation and the magnetotelluric theory will presently be described to show how they are connected with the study of dipole fields.

Geomagnetic Micropulsation

Geomagnetic micropulsations are small-amplitude high-frequency fluctuations of the earth's magnetic field. They are arbitrarily classified into three main categories: Pc, Pt and Pg.

Pc (continuous pulsations) is self-explanatory. It is a continuous series of regular geomagnetic oscillations

that may last for several hours and whose amplitude is a fraction of a γ ($1\ \gamma = 10^{-5}$ gauss). However the amplitude has been observed to increase with geomagnetic latitude and it attains maximum in the auroral zone. The range of periods of Pc varies but is usually observed between 10 - 60 sec. Very noticeable Pc's appear after the last phase of a magnetic storm and may persist for one or two days or even longer.

Pt (pulsation train) appears as several separate series of damped oscillations. The damping time of each series varies from a few to ten or twenty minutes. An entire Pt may last about an hour. The period range of these oscillations is from 40 - 100 sec., although they have been observed with superposition of 10 - 20 sec. oscillations. The amplitude of Pt's is larger than that of the Pc's, approximately .5 γ. These damped oscillations are usually observed at the commencement of bay disturbances, continuing until the maximum phase. However, during the decline of the bay disturbance no Pt pulsations are observed.

Pg (giant pulsations) are a series of oscillations of large amplitude which are sometimes as large as a few tens of γ's, giants compared with the previous two types. The period is also longer, being at least one minute and very often much longer. The giant pulsations are found at high latitudes near the auroral zone and their occurrence frequency is small. They are observed only a few times a year.

Some refinements on the above classification have been made by Troitskaya (1961). For example she has suggested

that the Pc's be subdivided into three groups with period range 5 - 15, 20 - 40 and 50 - 90 sec. She also introduced such nomenclatures as PP, SIP and IPDP for pulsations of pearl beating type, sudden irregular pulsations, and intervals of pulsations of diminishing periods, respectively.

Benioff (1960) has classified his observations into types A, B, C and D on amplitude-time display basis. He identifies all these different types of oscillations by their frequencies. He also has taken great care to associate them with phenomena such as sunspot number and auroral displays. Though no great objection can be raised against his system of nomenclature, it is nevertheless misleading to try to classify micropulsations by frequency together with a source, since at present no great amount of knowledge has yet been accumulated in connection with the generation of these oscillations. Furthermore, theorists have predicted the latitude dependence of hydromagnetic wave frequency (Obayashi and Jacobs, 1958). Observations have also shown this dependence (Jacobs and Sinno, 1960; Duncan, 1961). Furthermore, it is only too possible that oscillations of the same frequency may arise from different types of physical processes.

A number of detailed analyses have been made on available data to correlate cosmic events and micropulsations. Among these workers are Benioff (1960), Campbell (1960a, b), Hawkins (1958), Jenkins, Phillips and Maple (1960), Teply and Wenworth (1962), Troitskaya (1961) and many others. The correlated events include sunspot numbers, pulsating aurora,

meteors in the atmosphere, X-ray bursts from the sun, electron bunches above the ionosphere, cosmic ray intensity in the exosphere and the fluctuation of the intensity of the outer Van Allen belt. Of all these the correlation between auroral display and micropulsation has been most extensive. However, all the events mentioned above seem to exhibit some positive correlation with micropulsation. Despite the diversity in their studies, all authors favour the view that micropulsations are possibly the manifestation of the portion of energy associated with hydromagnetic waves in the ionosphere which propagate down to the surface of the earth through whatever mechanism there may exist.

Considerable amount of effort has been made to construct current systems in the lower part of the ionosphere and to determine the positions of such currents experimentally (Jacobs and Sinno, 1960; Campbell and Rees, 1961) with the conviction that they may partially be responsible for micropulsations registered on the surface of the earth. Some workers have reported observations which exhibit close relation with the electric and magnetic dipole fields (Bomke, 1962). These dipoles are conceived as lateral oscillations of electrons and closed-current systems in the lower part of the ionosphere. Up to now, very few works on dipole fields have been reported in connection with micropulsations, though a few workers (Law and Fanan, 1961; Weaver, 1961) have studied fields of a line source in this respect. This should suffice to suggest a reason to study the dipole fields with a new

incentive.

Magnetotelluric Theories

The properties of the oscillating natural electromagnetic fields registered at the surface of the earth should theoretically depend upon the nature of the source and the electromagnetic constants of the earth. A magnetotelluric theory is mainly concerned with the interrelation between the horizontal components of these fields.

L. Cagniard of France generalized his studies into a theory in 1953 (Cagniard, 1953). The essence of his theory can be summarized in the following points:

(a) Assumptions - Cagniard has assumed the existence of a horizontal telluric current sheet which is harmonic in time and uniform over a vast area. This telluric current sheet is considered to be induced by uniform plane electromagnetic waves impinging upon the surface of a flat stratified earth at an arbitrary angle of incidence. The sources of these waves have not been taken into account since they are considered to have no bearing upon the results of analysis.

(b) Analysis - the analysis is very simple. If one assumes the current sheet flowing in the x-direction resulting from a plane wave electrically polarized in the x-direction, then $E_y = E_z = 0$ and $E_x = E_x(z)$. The employment of the electric Hertz vector Π_e (Appendix I) yields

$$E_x = k^2\Pi_{ex}, \quad \Pi_{ey} = \Pi_{ez} = 0.$$

i.e. $\frac{\partial^2}{\partial z^2}E_x + k^2E_x = 0$ by putting in $\nabla^2\Pi_e + k^2\Pi_e = 0$.

The solution for this equation is then given by

$$E_x = Ae^{ikz} + Be^{-ikz}$$

since $H_y = i\omega\bar{\epsilon}\frac{\partial}{\partial z}E_x$, $H_x = H_z = 0$.

$$\therefore \quad H_y = - \omega\bar{\epsilon}k(Ae^{ikz} - Be^{-ikz})$$

where $\bar{\epsilon}$ is the complex permitivity, ω is the angular frequency (see Appendix I). By matching the boundary conditions between the media, one can obtain the constants A and B as functions of the electromagnetic constant of the earth, the thickness of the layers and the period of the wave. The ratio $|E_x/H_y|$, which is called the intrinsic impedence of the earth, has been computed by Cagniard for a two layered earth and different conductivity contrasts. This suggests a new means for geophysical exploration.

The two fundamental assumptions in Cagniard's theory, namely that the waves are plane and uniform over a vast area and that the source can be entirely neglected, have not been accepted without challenge. Wait (1954) had put a limitation on the application of Cagniard's theory. He showed that for magnetotelluric oscillations of frequency .1 cps on a homogeneous ground of conductivity $\sigma = 10^{-3}$ mho/m, the variation of E and H within 35 km must be very small, otherwise correction of second or higher orders of space derivatives of the field must be applied to Cagniard's theory. He pointed out that if the sources of the geomagnetic oscillations that are used

in magnetotelluric interpretation are situated at 100 km high, say, as a result of flowing currents in the lower part of the ionosphere, correction would be important for many frequencies.

For the interpretation of the stratification of the earth, Wait found it necessary to separate the electric and magnetic fields into frequency- and time-dependent components and then apply harmonic analysis to obtain the former from a certain assumption of the latter (for example, he worked out the transient case $H(t) = H_0$ for $t < 0$, and $H(t) = H_0 + \Delta H_0$ for $t > 0$). An impedance function is then obtained by comparing $E(\omega)$ and $H(\omega)$. This no doubt is a very complicated matter. As an alternative Wait suggested that instead of comparing $E_x(\omega)$ and $H_y(\omega)$ to evaluate the intrinsic impedance of the earth, one can assume a certain magnetic change with time and study the resulting time variation of the electric field to obtain the conductivities of the earth and the thickness of the layers. Although his method has not been used, his modification for Cagniard's theory has remained a token of danger to those who use the theory.

A.T. Price (1962) has investigated the effect of the source dimension upon the intrinsic impedance $| E_x/H_y |$. He has found that Cagniard's simple formula needs modification to take into account the dimensions of the field sources even when the field is global in scale and the region under investigation is much smaller. For example, Price has considered a case of very simple geological configuration, a homogeneous earth of a constant conductivity σ and has ob-

tained (in M.K.S.)

$$\frac{E_x}{H_y} = \frac{i\omega}{\sqrt{(\nu^2 + i\omega\sigma)}} = \sqrt{\frac{i\omega}{\sigma}}\,(1 - \frac{1}{2}\,\frac{\nu^2}{i\omega\sigma} + - - -), \text{ if } \nu \text{ is small} \qquad (1\text{-}1)$$

(ν is the separation constant in his derivation whose value will be discussed later).

In Price's notation, Wait's result as a modification to Cagniard's can be expressed as:

$$\frac{E_x}{H_y} = \sqrt{\frac{i\omega}{\sigma}}(1 - \frac{\nu^2}{2i\omega\sigma}) \qquad \text{(M.K.S.)} \qquad (1\text{-}2)$$

while Cagniard's intrinsic impedance for the same case is

$$\frac{E_x}{H_y} = \frac{1}{\sqrt{2\sigma T}}\, e^{+i\frac{\pi}{4}}$$

$$= \sqrt{\frac{i\omega}{4\pi\sigma}} \qquad \text{(e.m.u.)}$$

$$= \sqrt{\frac{i\omega}{\sigma}} \qquad \text{(M.K.S.)} \qquad (1\text{-}3)$$

(Note: $e^{+\frac{i\pi}{4}}$ instead of $e^{-\frac{i\pi}{4}}$ is given here because $e^{-i\omega t}$ has replaced $e^{+i\omega t}$ as in Cagniard's treatment)

These show that both Wait's and Cagniard's results are special cases of Price's by assigning small values to ν. Price points out that one can take $2\pi/\nu$ as a horizontal measure of the source dimension. Therefore in Cagniard's case, with $\nu = 0$, the dimension of the source is taken to be infinitely large. This corresponds to a plane wave. Wait's result is obtained by taking $\nu^2/\omega\sigma << 1$ or $\nu^2 << \omega\sigma$. This shows that Wait's approximation is valid for comparatively

large sources, which however are small compared with those considered by Cagniard. These two cases show that the concept of ν's being a reciprocal measure of the source dimension is quite self-consistent. However, the quantitative values of ν (or rather the dominating range of values) must be obtained from careful analysis. For example, one may compare the intrinsic impedance obtained by use of equation (1-1) and that obtained from the exact solution of a dipole or an infinite line current at finite height for both small and large radial distances. This comparision should give an estimate of the range of values of ν for a dipole source and a line current source. Price has estimated that the values of ν of interest in magnetotelluric studies will generally be within the range of 1.57×10^{-9} - 1.57×10^{-7} cm^{-1}.

1.4 Object of the Thesis

In view of the historical review in section 1.2 and the brief account of micropulsation and magnetotelluric method in section 1.3, the purposes of this thesis are described in the following three paragraphs:

(1) The first object is to derive mathematical expressions for the surface components of the electric and magnetic fields for horizontally and vertically oriented electric and magnetic dipoles elevated above a two-layered ground. While one can find fragmentary treatment of similar problems scattered throughout the literature of the last 30 years, he will

find an earnest attempt to give a rather self-contained treatment of all four problems in this thesis. The solutions in this thesis are exact and have not appeared in the literature. From these results many special cases previously treated individually by different authors can be obtained by specifying certain parameters. For example, the case for a dipole elevated above a homogeneous ground can be obtained by either putting $\sigma_1 = \sigma_2$ or letting the thickness of layer $D \longrightarrow \infty$ (or $D \longrightarrow 0$). Similarly one can obtain the cases for dipoles on the surface by letting the height of the dipoles approach zero. These cases will be worked out in the body of the thesis for checking purposes.

(2) For the last 30 years the complexity of the integrals in the results have kept investigators from going further than treating special cases. However with the high speed computers available, the study of the surface components of the dipole fields can be carried out with great detail and precision. A few interesting cases will be carried out with a high speed computer in this thesis.

(3) This study is not intended to throw light on the origin of micropulsations. However, it is hoped that it will assist to further the understanding of Cagniard's magnetotelluric theory. Since in this theory an important assumption is that incident waves are uniform plane waves, localized cylindrical waves from a near dipole source should therefore set a worst possible limit on the theory. Consequently, a worst possible result can be expected from the application of

this theory. Indirectly, this will partially answer the question of the degree to which the micropulsations observed at the surface of the earth can be considered plane waves.

II. SIMPLY ORIENTED DIPOLES AND THEIR E. M. FIELDS ON THE SURFACE OF A 2-LAYERED EARTH

2.1 Formulation of the Problems and Solutions

In this section the vertical and horizontal magnetic and electric dipoles elevated above a 2-layered ground are to be treated as four separate cases. The earth will be taken as flat with horizontal plane boundaries. The Hertz vectors will be derived for each case and the field vectors will be expressed in terms of these vectors. As this section is designed to give a self-contained treatment of all four problems, a considerable amount of mathematics will be given, though conciseness will remain the chief objective throughout. The whole treatment will follow the method developed by Sommerfeld in his two papers (1909 and 1926), and summarized in his book "Partial differential equations" (Sommerfeld 1949).

M.K.S. units will be used and the time dependent factor $e^{-i\omega t}$ suppressed.

Case 1. Vertical Magnetic Dipole

Since the fields of a vertical dipole possess cylindrical symmetry, we shall use the polar coordinate system. The geometric configuration is shown in Figure 1.

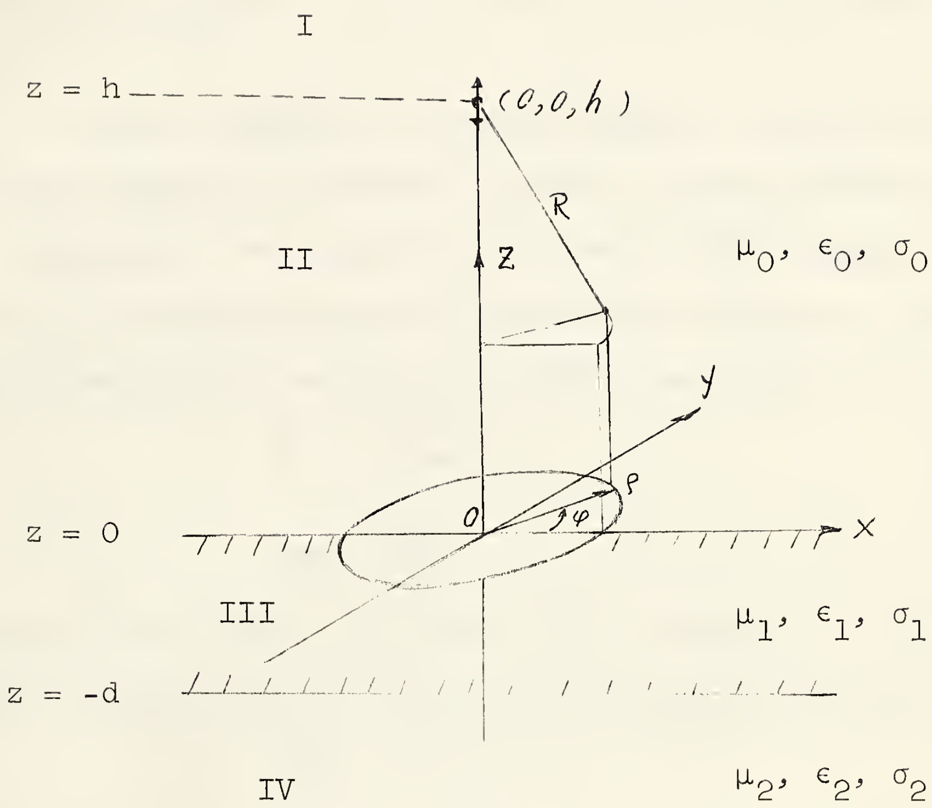


Figure 1. Coordinate system and the orientation of the vertical dipole

The dipole is situated at $z = h$, $\rho = 0$. The ground-air interface is designated by the plane $z = 0$. The first layer has thickness d and the substratum extends from $z = -d$ to $z = -\infty$. The three regions are electromagnetically characterized by μ_0, ϵ_0, σ_0, μ_1, ϵ_1, σ_1, and μ_2, ϵ_2, σ_2 as shown in Figure 1.

We can imagine a vertical magnetic dipole as an oscillating magnetic "current" element in the vertical direction. Therefore the magnetic Hertz vector $\vec{\Pi}_m$ (Appendix I-2) as well as the vector potential $\vec{A}'$ have the direction of the current element in free space (p. 238, Sommerfeld, 1949), i.e.

$$\vec{\Pi}_m = \hat{k}\,\Pi_{mz} \tag{2-1}$$

$$\Pi_{m\varphi} = \Pi_{m\rho} = 0 \tag{2-2}$$

Consequently the vector equation (I-22, Appendix I-2) becomes a scalar equation and by changing the subscript we have

$$\nabla^2\Pi_s + k^2\Pi_s = 0. \tag{2-3}$$

This is the 3-dimensional Helmholtz equation whose solution is well known. However, (2-3) does not include the source. In order to include the source at which the Hertz potential becomes infinite we must replace (2-3) by

$$\nabla^2\Pi_p + k^2\Pi_p = -M \tag{2-4}$$

where M is the magnetic moment density (Stratton 1941, p. 30).

If we further assume the dipole moment as concentrated at one point (0,0,h) at which the magnetic moment den-

sity is infinite then we can rewrite (2-4) as

$$\nabla^2 \Pi_p + k^2 \Pi_p = - M_0 \delta(R) \tag{2-5}$$

where M_0 is the total magnetic moment of the dipole and $R^2 = \rho^2 + (z - h)^2$. $\delta(R)$ is the 3-dimensional delta function having the property

$$\delta(R) = 0 , \qquad R \neq 0$$

$$\int_V \delta(R) dv = 1 \qquad \text{over all space.}$$

The solution for (2-5) is the well known Green's function for the Helmholtz equation with the necessary boundary conditions (Morse and Feshbach, p. 804) and is of the form:

$$\Pi_p = \frac{M_0 e^{+ikR}}{4\pi R}$$

The exponential being chosen positive to yield out-going waves when coupled with $e^{-i\omega t}$. Since the magnetic moment is entirely arbitrary for our later development, it is chosen as 4π and

$$\Pi_p = \frac{e^{ikR}}{R} \tag{2-6}$$

Equation (2-6) describes the primary spherical radiation fields of a magnetic dipole of strength 4π amp-meter^2.

Due to the linearity of (2-5), one can superimpose the solution of the homogeneous equation (2-3) upon (2-6) to obtain a complete solution Π, or

$$\Pi = \Pi_p + \Pi_s \tag{2-7}$$

Π_s can be interpreted physically as a secondary potential

which aries from the presence of the earth, and the secondary waves derived from it are the diffracted waves. Π_s is so chosen that it will satisfy all the boundary conditions between the media and is finite everywhere, including the source region.

From the theory of cylindrical harmonics, one can write down the solution of (2-3):

$$\Pi_s = R(\lambda)\begin{matrix}\cos\\ \sin\end{matrix}\; n\varphi \exp(\pm(\lambda^2 - k^2)^{1/2} z)\begin{matrix}J_n\\ Y_n\end{matrix}(\lambda\rho) \qquad (2\text{-}8)$$

$n = 0, 1, 2 \ldots$

λ being the separation constant and $R(\lambda)$ an arbitrary function of λ.

The choice of solution depends on the nature of the problem. Since our problem requires Π_s to be angularly independent and zero at $\rho = \infty$, we choose

$$\Pi_s = R(\lambda)\exp(\pm(\lambda^2 - k^2)^{1/2} z) J_0(\lambda\rho) \qquad (2\text{-}9)$$

The sign of the exponential will be chosen to ensure $\Pi_s \longrightarrow 0$ as $z \longrightarrow \pm\infty$.

In order to have a general expression for Π_s, we must integrate (2-9) over all values of λ, i.e.

$$\Pi_s = \int_0^\infty R(\lambda) J_0(\lambda\rho) e^{\pm(\lambda^2 - k^2)^{1/2} z}\, d\lambda \qquad (2\text{-}10)$$

By use of Sommerfeld's integral (Sommerfeld, 1949, p. 241), we change Π_p into an infinite integral,

$$\Pi_p = e^{ikR}/R = \int_0^\infty \frac{\lambda}{p} J_0(\lambda\rho) e^{-p|z-h|} d\lambda \qquad (2\text{-}11)$$

where $p^2 = (\lambda^2 - k^2)$. Combining (2-10) and (2-11)

$$\Pi = \Pi_p + \Pi_s = \int_0^\infty \frac{\lambda}{p} J_0(\lambda\rho) e^{-p|z-h|}\, d\lambda + \int_0^\infty R_1(\lambda) J_0(\lambda\rho) e^{pz}\, d\lambda$$

$$+ \int_0^\infty R_2(\lambda) J_0(\lambda\rho) e^{-pz}\, d\lambda \qquad (2\text{-}12)$$

For each region I, II, III and IV in Fig. 1, we can write down the Hertz potential, replacing R by F, and p by $p_i = (\lambda^2 - k_i^2)^{1/2}$, $k_i = (\omega^2 \mu \bar{\epsilon}_i)$, $\bar{\epsilon}_i$ being the complex permitivity.

$$\Pi_I = \int_0^\infty \left(\frac{\lambda}{p_0} e^{-p_0(z-h)} + F_0(\lambda) e^{-p_0(z+h)}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}13)$$

$$\Pi_{II} = \int_0^\infty \left(\frac{\lambda}{p_0} e^{+p_0(z-h)} + F_0(\lambda) e^{-p_0(z+h)}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}14)$$

$$\Pi_{III} = \int_0^\infty \left(F_1(\lambda) e^{p_1 z - p_0 h} + F_2(\lambda) e^{-p_1 z - p_0 h}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}15)$$

$$\Pi_{IV} = \int_0^\infty F_3(\lambda) e^{+p_2 z + (p_2 - p_1)d - p_0 h} J_0(\lambda\rho) d\lambda \qquad (2\text{-}16)$$

The exponents are chosen for convenience. The F's are to be determined by the boundary conditions.

By (I-23) and (I-24) and the fact that $\vec{\Pi}$ has only an angularly independent z-component, we have an H_z and the following two horizontal components:

$$H_\rho = \frac{\partial^2}{\partial\rho\partial z} \Pi, \qquad E_\varphi = i\omega\mu \frac{\partial}{\partial\rho} \Pi \qquad (2\text{-}17,\ 2\text{-}18)$$

H_ρ and E_φ are required to be continuous across the boundaries.

At $z = 0$, the following must hold:

$$\frac{\partial^2}{\partial\rho\partial z}\Pi_{II} = \frac{\partial^2}{\partial\rho\partial z}\Pi_{III}\,, \quad \mu_0 \frac{\partial}{\partial\rho}\Pi_{II} = \mu_1 \frac{\partial}{\partial\rho}\Pi_{III}$$

or $$\frac{\partial}{\partial z}\Pi_{II} = \frac{\partial}{\partial z}\Pi_{III}\,, \qquad \mu_0\Pi_{II} = \mu_1\Pi_{III} \qquad (2\text{-}19,\ 2\text{-}20)$$

since all values of ρ are common to both vectors along the boundary. Applying (2-19, 2-20) to (2-14, 2-15) and equating the resultant integrands we have:

$$F_0(\lambda) + \frac{p_1}{p_0}F_1(\lambda) - \frac{p_1}{p_0}F_2(\lambda) = \frac{\lambda}{p_0} \qquad (2\text{-}21)$$

and

$$F_0(\lambda) - \frac{\mu_1}{\mu_0}F_1(\lambda) - \frac{\mu_1}{\mu_0}F_2(\lambda) = -\frac{\lambda}{p_0} \qquad (2\text{-}22)$$

At $z = -d$, similarly we apply

$$\frac{\partial}{\partial z}\Pi_{III} = \frac{\partial}{\partial z}\Pi_{IV}\,, \quad \mu_1\Pi_{III} = \mu_2\Pi_{IV} \qquad (2\text{-}23,\ 2\text{-}24)$$

to (2-15, 2-16) and obtain

$$\frac{p_1}{p_2}\left\{F_1(\lambda) - F_2(\lambda)e^{2p_1 d}\right\} = F_3(\lambda) \qquad (2\text{-}25)$$

$$\frac{\mu_1}{\mu_2}\left\{F_1(\lambda) + F_2(\lambda)e^{2p_1 d}\right\} = F_3(\lambda) \qquad (2\text{-}26)$$

Subtracting (2-22) from (2-21) and (2-26) from (2-25), we have

$$\left(\frac{p_1}{p_0} + \frac{\mu_1}{\mu_0}\right)F_1(\lambda) - \left(\frac{p_1}{p_0} - \frac{\mu_1}{\mu_0}\right)F_2(\lambda) = \frac{2\lambda}{p_0} \qquad (2\text{-}27)$$

$$\left(\frac{p_1}{p_2} - \frac{\mu_1}{\mu_2}\right)F_1(\lambda) - \left(\frac{p_1}{p_2} + \frac{\mu_1}{\mu_2}\right)F_2(\lambda)e^{2p_1 d} = 0 \qquad (2\text{-}28)$$

Let $A = {}^{p_1}/p_0$, $B = {}^{p_1}/p_2$, $C = {}^{\mu_1}/\mu_0$, $D = {}^{\mu_1}/\mu_2$ and solve for

$F_1(\lambda)$ and $F_2(\lambda)$ from (2-26) and (2-27):

$$\Delta = \begin{vmatrix} (A+C), & -(A-C) \\ (B-D), & -(B+D)e^{2p_1d} \end{vmatrix} = -(A+C)(B+D)e^{2p_1d} + (A-C)(B-D) \tag{2-29}$$

$$F_1(\lambda) = \frac{1}{\Delta} \begin{vmatrix} 2\lambda/p_0, & -(A-c) \\ 0 \quad, & -(B+D)e^{2p_1d} \end{vmatrix} = -\frac{1}{\Delta} \times \frac{2\lambda}{p_0} \times (B+D)e^{2p_1d} \tag{2-30}$$

$$F_2(\lambda) = \frac{1}{\Delta} \begin{vmatrix} (A+C), & 2\lambda/p_0 \\ (B-D), & 0 \end{vmatrix} = -\frac{1}{\Delta}\frac{2\lambda}{p_0} \times (B-D) \tag{2-31}$$

Substituting (2-29, 2-30, 2-31) in (2-21)

$$F_0(\lambda) = \frac{\lambda}{p_0} - \frac{p_1}{p_0}\left(F_1(\lambda) - F_2(\lambda)\right)$$

$$= \frac{\lambda}{p_0} - \frac{p_1}{p_0}\left(\frac{2\lambda}{p_0}\right) \frac{(B-D) - (B+D)e^{2p_1d}}{(A-C)(B-D)-(A+C)(B+D)e^{2p_1d}}$$

$$= \frac{\lambda}{p_0}\left\{1 - \frac{2p_1\mu_0\left[(p_1\mu_2-p_2\mu_1)-(p_1\mu_2+p_2\mu_1)e^{2p_1d}\right]}{(p_1\mu_0-p_0\mu_1)(p_1\mu_2-p_2\mu_1)-(p_1\mu_0+p_0\mu_1)(p_1\mu_2+p_2\mu_1)e^{2p_1d}}\right\}$$

or

$$F_0(\lambda) = \frac{\lambda}{p_0}\left\{\frac{(p_1\mu_0+p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1d} - (p_1\mu_0-p_0\mu_1)(p_1\mu_2+p_2\mu_1)}{(p_1\mu_0+p_0\mu_1)(p_1\mu_2+p_2\mu_1)-(p_1\mu_0-p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1d}}\right\} \tag{2-32}$$

(2-32) is exact for a 2-layered earth.

If we put $\epsilon_0 = 0$, $\mu_0 = \mu_1 = \mu_2$ then $p_0 = \lambda$

$$F_0(\lambda) = \frac{(p_1+\lambda)(p_1-p_2)e^{-2p_1d} - (p_1-\lambda)(p_1+p_2)}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1d}} \tag{2-33}$$

Equation (2-33) was used by Wait (1958).

The exact solution for a homogeneous ground can be obtained by letting $d \longrightarrow \infty$, $d \longrightarrow 0$ or $p_1 = p_2$,

$$F_0(\lambda) = \frac{\lambda}{p_0}\left\{\frac{p_0\mu_1 - p_1\mu_0}{p_0\mu_1 + p_1\mu_0}\right\} \tag{2-34}$$

Using the approximation quoted above, one has

$$F_0(\lambda) = \frac{\lambda - p_1}{\lambda + p_1} \tag{2-35}$$

To obtain the electric and magnetic field equations in region II, use (I-23, I-24) and (2-14). Solutions for practical purposes can be obtained by approximating (2-32). All components of the electromagnetic fields for all cases will be given in section 2.2.

Case 2. Horizontal Magnetic Dipole

For a horizontal dipole it is convenient to use the Cartesian coordinates with the dipole aligned in the x-direction, as shown in Figure 2. Since the order of symmetry is lower here than in the previous case, a Hertz vector with a single component in the direction of the dipole is no longer adequate to satisfy all boundary conditions.

The addition of a z-component is necessary for this purpose (Sommerfeld, 1949, p. 258).

We write

$$\vec{\Pi} = \hat{i}\,\Pi_x + \hat{k}\,\Pi_z\ , \qquad \Pi_y = 0$$

or

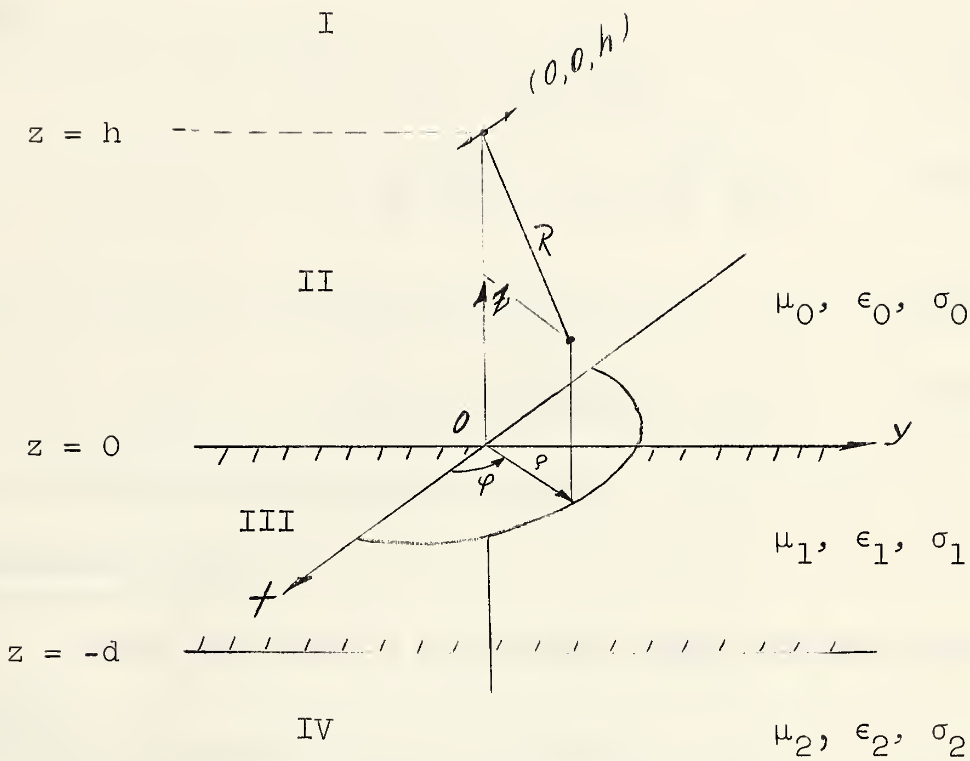


Figure 2. Coordinate system and the orientation of the horizontal dipole

$$H_x = k^2 \Pi_x + \frac{\partial}{\partial x} \operatorname{div} \Pi \quad , \qquad H_y = \frac{\partial}{\partial y} \operatorname{div} \Pi \qquad (2\text{-}36,\ 2\text{-}37)$$

$$E_x = i\mu\omega \frac{\partial}{\partial y} \Pi_z \quad , \qquad E_y = i\mu\omega \left(\frac{\partial}{\partial z} \Pi_x - \frac{\partial}{\partial z} \Pi_z\right) \qquad (2\text{-}38,\ 2\text{-}39)$$

By use of (2-36, 2-37, 2-38, 2-39) we can transform the ordinary boundary conditions for tangential E and H into the following:

$$\mu_j \Pi_{zj} = \mu_{j+1} \Pi_{zj+1} \qquad (2\text{-}40)$$

$$\mu_j \frac{\partial}{\partial z} \Pi_{xj} = \mu_{j+1} \frac{\partial}{\partial z} \Pi_{xj+1} \qquad (2\text{-}41)$$

$$\nabla \cdot \Pi_j = \nabla \cdot \Pi_{j+1} \qquad (2\text{-}42)$$

$$k_j^2 \Pi_{xj} = k_{j+1}^2 \Pi_{xj+1} \qquad (2\text{-}43)$$

j and j+1 designating adjacent regions.

Determination of Π_x

As in the case of a vertical dipole we can write Π_x as follows:

$$\Pi_{Ix} = \int_0^\infty \left(\frac{\lambda}{p_0} e^{-p_0(z-h)} + G_0(\lambda) e^{-p_0(z+h)}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}44)$$

$$\Pi_{IIx} = \int_0^\infty \left(\frac{\lambda}{p_0} e^{p_0(z-h)} + G_0(\lambda) e^{-p_0(z+h)}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}45)$$

$$\Pi_{IIIx} = \int_0^\infty \left(G_1(\lambda) e^{p_1 z - p_0 h} + G_2(\lambda) e^{-p_1 z - p_0 h}\right) J_0(\lambda\rho) d\lambda \qquad (2\text{-}46)$$

$$\Pi_{IVx} = \int_0^\infty (G_3(\lambda) e^{p_2 z + (p_2 - p_1) d - p_1 h} J_0(\lambda\rho) d\lambda \qquad (2\text{-}47)$$

In order to solve for the G-functions, we apply boundary conditions (2-41, 2-43) to the Π_x's.

At $z = 0$, apply (2-41) to (2-45, 2-46) and equate the integrands. The result is

$$G_0(\lambda) = \frac{\lambda}{p_0} - \frac{\mu_1 p_1}{\mu_0 p_0}\left\{G_1(\lambda) - G_2(\lambda)\right\} \qquad (2\text{-}48)$$

The result of (2-43) at $z = 0$ is

$$G_0(\lambda) = -\frac{\lambda}{p_0} + n_{10}^2\left\{G_1(\lambda) + G_2(\lambda)\right\} \qquad (2\text{-}49)$$

where $n_{ij}^2 = k_i^2/k_j^2$.

Applying the same boundary conditions at $z = -d$, one has

$$\frac{\mu_1 p_1}{\mu_2 p_2}\left\{G_1(\lambda) - G_2(\lambda)e^{2p_1 d}\right\} = G_3(\lambda) \qquad (2\text{-}50)$$

$$n_{12}^2\left\{G_1(\lambda) + G_2(\lambda)e^{2p_1 d}\right\} = G_3(\lambda) \qquad (2\text{-}51)$$

Subtract (2-49) from (2-48) and (2-51) from (2-50)

$$\left(\frac{\mu_1 p_1}{\mu_0 p_0} + n_{10}^2\right)G_1(\lambda) - \left(\frac{\mu_1 p_1}{\mu_0 p_0} - n_{10}^2\right)G_2(\lambda) = \frac{2\lambda}{p_0} \qquad (2\text{-}52)$$

$$\left(\frac{\mu_1 p_1}{\mu_2 p_2} - n_{12}^2\right)G_1(\lambda) - \left(\frac{\mu_1 p_1}{\mu_2 p_2} + n_{12}^2\right)G_2(\lambda)e^{2p_1 d} = 0 \qquad (2\text{-}53)$$

Since $n_{ij}^2 = k_i^2/k_j^2 = \dfrac{\omega^2\mu_i\epsilon_i}{\omega^2\mu_j\epsilon_j} = \dfrac{\mu_i\epsilon_i}{\mu_j\epsilon_j}$, ϵ being the complex permittivity, equivalent to $\bar{\epsilon}$ in Appendix I with the bar removed, (2-52, 2-53) can be rewritten as follows:

$$\left(\frac{p_1}{p_0} + \frac{\epsilon_1}{\epsilon_0}\right) G_1(\lambda) - \left(\frac{p_1}{p_0} - \frac{\epsilon_1}{\epsilon_0}\right) G_2(\lambda) = \frac{2\lambda}{p_0}\left(\frac{\mu_0}{\mu_1}\right) \tag{2-54}$$

$$\left(\frac{p_1}{p_2} - \frac{\epsilon_1}{\epsilon_2}\right) G_1(\lambda) - \left(\frac{p_1}{p_2} + \frac{\epsilon_1}{\epsilon_2}\right) G_2(\lambda) e^{2p_1 d} = 0 \tag{2-55}$$

By comparing (2-21) and (2-48), (2-27) and (2-54), and (2-28) and (2-55) one can immediately write down the expressions for $G_1(\lambda)$, $G_2(\lambda)$, and $G_0(\lambda)$.

$$G_1(\lambda) = -\frac{1}{\Delta}\frac{2\lambda}{p_0}\left(\frac{\mu_0}{\mu_1}\right)\left(\frac{p_1}{p_2} + \frac{\epsilon_1}{\epsilon_2}\right)e^{2p_1 d} \tag{2-56}$$

$$G_2(\lambda) = -\frac{1}{\Delta}\frac{2\lambda}{p_0}\left(\frac{\mu_0}{\mu_1}\right)\left(\frac{p_1}{p_2} - \frac{\epsilon_1}{\epsilon_2}\right) \tag{2-57}$$

where

$$\Delta = \left(\frac{p_1}{p_0} - \frac{\epsilon_1}{\epsilon_0}\right)\left(\frac{p_1}{p_2} - \frac{\epsilon_1}{\epsilon_2}\right) - \left(\frac{p_1}{p_0} + \frac{\epsilon_1}{\epsilon_0}\right)\left(\frac{p_1}{p_2} + \frac{\epsilon_1}{\epsilon_2}\right)e^{2p_1 d}$$

and

$$G_0(\lambda) = \frac{\lambda}{p_0}\;\frac{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1 d} - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1) - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1 d}} \tag{2-58}$$

Equation (2-58) is exact and approximations can be obtained by putting in special values for ϵ_i and μ_i.

For a homogeneous earth, we can let $d \longrightarrow 0$, $d \longrightarrow \infty$ or $\mu_1 = \mu_2$, $\epsilon_1 = \epsilon_2$ and have

$$G_0(\lambda) = \frac{\lambda}{p_0}\left\{\frac{\epsilon_1 p_0 - p_1\epsilon_0}{\epsilon_1 p_0 + p_1\epsilon_0}\right\} \tag{2-59}$$

If we substitute (2-59) into (2-44) with $h = 0$, we have

$$\Pi_{Ix} = 2\int_0^\infty \frac{\epsilon_1 p_0}{\epsilon_1 p_0 + p_1\epsilon_0}\, e^{-p_0 z}\, J_0(\lambda\rho)d\lambda$$

This is Sommerfeld's x-component of the Hertz vector for a horizontal dipole on the surface of a homogeneous earth.

The other G-functions can be obtained easily from (2-54, 2-55). Since we are only interested in the Region II, the calculation of these G's are dispensed with.

Determination of Π_z

Since Π_z is an induced effect it has to satisfy only the homogeneous Helmholtz equation (2-3) while Π_x has to satisfy (2-4) which includes the direct influence of the source. Therefore Π_z must take the form

$$\Pi_z = \left\{\begin{matrix}\cos\\ \sin\end{matrix} n\varphi\right\}\int_0^\infty R(\lambda)e^{\pm(\lambda^2-k^2)^{1/2}z}\left\{\begin{matrix}J_n(\lambda\rho)\\ Y_n\end{matrix}\right\} d\lambda \tag{2-60}$$

as follows from (2-8). The choice of Π_z depends upon the boundary conditions. Since Π_z is required to be finite as $\rho \longrightarrow \infty$, $Y_n(\lambda\rho)$ must be discarded. Simple geometry requires $\Pi_z = 0$ at $\varphi = \pm\frac{\pi}{2}$ to give $\vec{H} = H_x\hat{i}$ in the plane $x = 0$. We shall choose

$$\Pi_z = \cos\varphi \int_0^\infty R(\lambda)e^{\pm(\lambda^2-k^2)^{1/2}z}\, J_1(\lambda\rho)d\lambda \tag{2-61}$$

which will later be shown to meet all boundary conditions. For each region the z-components of the Hertz vector are:

$$\Pi_{Iz} = \Pi_{IIz} = \cos\varphi \int_0^\infty S_0(\lambda) J_1(\lambda\rho) e^{-p_0(z+h)}\, d\lambda \qquad (2\text{-}62)$$

$$\Pi_{IIIz} = \cos\varphi \int_0^\infty J_1(\lambda\rho) \left\{ S_1(\lambda) e^{p_1 z - p_0 h} + S_2(\lambda) e^{-p_1 z - p_0 h} \right\} d\lambda \qquad (2\text{-}63)$$

$$\Pi_{IVz} = \cos\varphi \int_0^\infty S_3(\lambda) J_1(\lambda\rho) e^{p_2 z + (p_2 - p_1)d - p_0 h}\, d\lambda \qquad (2\text{-}64)$$

where $S_i(\lambda)$ are to be determined by the necessary boundary conditions (2-40, 2-42).

Applying (2-40) to (2-62, 2-63, 2-64) at $z = 0$ and $z = -d$, we have

$$S_0(\lambda) = \frac{\mu_1}{\mu_0} \left\{ S_1(\lambda) + S_2(\lambda) \right\} \qquad (2\text{-}65)$$

$$S_3(\lambda) = \frac{\mu_1}{\mu_2} \left\{ S_1(\lambda) + S_2(\lambda) e^{2p_1 d} \right\} \qquad (2\text{-}66)$$

Boundary condition (2-42) can be rewritten as:

$$\frac{\partial}{\partial x} \Pi_{xj} - \frac{\partial}{\partial x} \Pi_{x\,j+1} = \frac{\partial}{\partial z} \Pi_{z\,j+1} - \frac{\partial}{\partial z} \Pi_{zj} .$$

At $z = 0$, using $\vec{\Pi}_{II}$ and $\vec{\Pi}_{III}$, (2-45, 2-46) and (2-62, 2-63), we have

$$\frac{\partial}{\partial x} \int_0^\infty \left\{ \frac{\lambda}{p_0} + G_0(\lambda) - G_1(\lambda) - G_2(\lambda) \right\} e^{-p_0 h} J_0(\lambda\rho)\, d\lambda$$

$$= \cos\varphi \int_0^\infty \left\{ p_1 (S_1(\lambda) - S_2(\lambda)) + p_0 S_0(\lambda) \right\} J_1(\lambda\rho) e^{-p_0 h}\, d\lambda \qquad (2\text{-}67)$$

Since $\frac{\partial}{\partial x} J_0(\lambda\rho) = \cos\varphi\cdot(-\lambda)J_1(\lambda\rho)$, (2-67) becomes

$$\int_0^\infty \left\{(-\lambda)\left[\frac{\lambda}{p_0} + G_0(\lambda) - G_1(\lambda) - G_2(\lambda)\right] - \left[p_1(S_1(\lambda)-S_2(\lambda))+p_0S_0(\lambda)\right]\right\}$$

$$J_1(\lambda\rho)e^{-p_0h}\,d\lambda = 0 \qquad (2\text{-}68)$$

$$\therefore\ \lambda(G_1(\lambda)+G_2(\lambda)-\frac{\lambda}{p_0}-G_0(\lambda)) = p_1(S_1(\lambda)-S_2(\lambda))+p_0S_o(\lambda) \qquad (2\text{-}69)$$

At $z = -d$, using $\vec{\Pi}_{III}$ and $\vec{\Pi}_{IV}$ (2-45, 2-46, 2-58, 2-59), we have

$$\int_0^\infty \left\{(-\lambda)\left[G_1(\lambda)+G_2(\lambda)e^{2p_1d}-G_3(\lambda)\right] - \left[p_2S_3(\lambda)-p_1(S_1(\lambda)\right.\right.$$

$$\left.\left.-S_2(\lambda)e^{2p_1d})\right]\right\} e^{-p_1d-p_0h} J_1(\lambda\rho)d\lambda = 0 \qquad (2\text{-}70)$$

or

$$\lambda\left\{G_3(\lambda)-G_1(\lambda)-G_2(\lambda)e^{2p_1d}\right\} = p_2S_3(\lambda)-p_1S_1(\lambda)+p_1S_2(\lambda)e^{2p_1d} \qquad (2\text{-}71)$$

To solve for $S_1(\lambda)$, $S_2(\lambda)$ and $S_3(\lambda)$, we rewrite (2-65, 2-69, 2-66, 2-71) as follows:

$$S_0(\lambda) = \frac{\mu_1}{\mu_0}\left\{S_1(\lambda) + S_2(\lambda)\right\} \qquad (2\text{-}72)$$

$$S_0(\lambda) = \frac{p_1}{p_0}\left\{S_2(\lambda)-S_1(\lambda)\right\} + \frac{\lambda}{p_0}\left\{G_1(\lambda)+G_2(\lambda) - \frac{\lambda}{p_0} - G_0(\lambda)\right\} \qquad (2\text{-}73)$$

$$S_3(\lambda) = \frac{\mu_1}{\mu_2}\left\{S_1(\lambda) + S_2(\lambda)e^{2p_1d}\right\} \qquad (2\text{-}74)$$

$$S_3(\lambda) = \frac{p_1}{p_2}\left\{S_1(\lambda)-S_2(\lambda)e^{2p_1d}\right\} + \frac{\lambda}{p_2}\left\{G_3(\lambda)-G_1(\lambda)-G_2(\lambda)e^{2p_1d}\right\} \qquad (2\text{-}75)$$

Subtracting (2-73, 2-75) from (2-72, 2-74) we have

$$\left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right) S_1(\lambda) + \left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0}\right) S_2(\lambda) = \frac{\lambda}{p_0} W(\lambda) \qquad (2\text{-}76)$$

$$\left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right) S_1(\lambda) + \left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d} S_2(\lambda) = \frac{\lambda}{p_2} U(\lambda) \qquad (2\text{-}77)$$

where

$$W(\lambda) = G_1(\lambda) + G_2(\lambda) - G_0(\lambda) - \frac{\lambda}{p_0}$$

$$= n_{01}^2 (G_0(\lambda) + \frac{\lambda}{p_0}) - (G_0(\lambda) + \frac{\lambda}{p_0})$$

$$= (n_{01}^2 - 1)(G_0(\lambda) + \frac{\lambda}{p_0}) \qquad (2\text{-}78)$$

where $G_0(\lambda)$ is given by (2-58).

$$U(\lambda) = G_3(\lambda) - G_1(\lambda) - G_2(\lambda) e^{2p_1 d}$$

$$= n_{12} \left\{ G_1(\lambda) + G_2(\lambda) e^{2p_1 d} \right\} - \left\{ G_1(\lambda) + G_2(\lambda) e^{2p_1 d} \right\}$$

$$= (n_{12}^2 - 1)(G_1(\lambda) + G_2(\lambda) e^{2p_1 d}$$

Substitute (2-56, 2-57) for $G_1(\lambda)$ and $G_2(\lambda)$

$$U(\lambda) = - \frac{1}{\Delta} \frac{4\lambda}{p_0} (\frac{\mu_0}{\mu_1})(\frac{p_1}{p_2}) e^{2p_1 d} \cdot (n_{12}^2 - 1)$$

$$= \frac{4\lambda\mu_0 p_1}{\mu_1} \frac{\epsilon_0 \epsilon_2 (n_{12}^2 - 1)}{(p_1\epsilon_0 + p_0\epsilon_1)(p_1\epsilon_2 + p_2\epsilon_1) - (p_1\epsilon_0 - p_0\epsilon_1)(p_1\epsilon_2 - p_2\epsilon_1) e^{-2p_1 d}}$$

(2-79)

Solving for $S_1(\lambda)$ and $S_2(\lambda)$ from (2-76, 2-77), let

$$D(\lambda) = \begin{vmatrix} \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right), & \left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0}\right) \\ \left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right), & \left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d} \end{vmatrix} = \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right)\left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d}$$

$$- \left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0}\right)\left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right) \tag{2-80}$$

$$S_1(\lambda) = \frac{1}{D(\lambda)} \begin{vmatrix} \frac{\lambda}{p_0} W(\lambda), & \left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0}\right) \\ \frac{\lambda}{p_2} U(\lambda), & \left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d} \end{vmatrix} = \frac{1}{D(\lambda)} \left\{ \frac{\lambda}{p_0} W(\lambda) \right.$$

$$\left. \times \left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d} - \frac{\lambda}{p_2} U(\lambda)\left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0}\right) \right\} \tag{2-81}$$

$$S_2(\lambda) = \frac{1}{D(\lambda)} \begin{vmatrix} \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right), & \frac{\lambda}{p_0} W(\lambda) \\ \left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right), & \frac{\lambda}{p_2} U(\lambda) \end{vmatrix} = \frac{1}{D(\lambda)} \left\{ \frac{\lambda}{p_2} U(\lambda) \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right) \right.$$

$$\left. - \frac{\lambda}{p_0} W(\lambda) \left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right) \right\} \tag{2-82}$$

From (2-72, 2-81, 2-82) we have

$$S_0(\lambda) = \frac{\mu_1}{\mu_0} \cdot \frac{1}{D(\lambda)} \cdot \left\{ \left[\left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2}\right) e^{2p_1 d} - \left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2}\right) \right] \cdot \frac{\lambda}{p_0} W(\lambda) \right.$$
$$\left. - 2 \cdot \frac{\lambda}{p_2} \cdot U(\lambda) \right\} \tag{2-83}$$

where $W(\lambda)$ and $U(\lambda)$ are given by (2-78, 2-79).

Since (2-83) is an extremely complicated expression, it is desirable to check it with some special cases at this point.

1. Homogeneous earth, $\mu_1 = \mu_2$, $\epsilon_1 = \epsilon_2$ $\therefore$ $p_1 = p_2$

$$U(\lambda) = 0 \; , \qquad n_{12}^2 = 1$$

$$G_0(\lambda) = \frac{\lambda}{p_0} \frac{(p_0\epsilon_1 - p_1\epsilon_0)}{(p_0\epsilon_1 + p_1\epsilon_0)}$$

$$D(\lambda) = \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right)\left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_0}\right) e^{2p_1 d}$$

$$S_0(\lambda) = \frac{\mu_1}{\mu_0} \cdot \frac{1}{\left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0}\right)} \cdot \frac{\lambda}{p_0} \; W(\lambda)$$

$$= \frac{\lambda}{\left(p_0 + p_1 \frac{\mu_0}{\mu_1}\right)} \left(\frac{\lambda}{p_0}\right) \left(\frac{2p_0\epsilon_1}{p_0\epsilon_1 + p_1\epsilon_0}\right) (n_{01}^2 - 1)$$

If we let $\mu_0 = \mu_1$, then $\dfrac{\epsilon_0}{\epsilon_1} = \dfrac{k_0^2}{k_1^2} = n_{01}^2$

$$S_0(\lambda) = \frac{2\lambda^2}{(p_1 + p_0)} \frac{(k_0^2 - k_1^2)}{(k_0^2 p_1 - k_1^2 p_0)}$$

and for a homogeneous earth with $\mu_0 = \mu_1$, (2-62) becomes

$$\Pi_{IIz} = \cos\varphi \int_0^\infty \frac{2\lambda^2 (k_0^2 - k_1^2)}{(p_1+p_0)(k_0^2 p_1 - k_1^2 p_0)} \; J_1(\lambda\rho) e^{-p_0(z+h)} \; d\lambda$$

$$= 2 \frac{\partial}{\partial x} \int_0^\infty \frac{(k_1^2-k_0^2)\lambda J_0(\lambda\rho)}{(p_1+p_0)(k_0^2p_1+k_1^2p_0)} e^{-p_0(z+h)} d\lambda \qquad (2\text{-}84)$$

If we put h = 0, the horizontal dipole being situated on the surface of a homogeneous earth, (2-84) becomes the same as that quoted by Wait (1953).

2. A second case we can check with is when $\mu_0 = \mu_1 = \mu_2$, $\epsilon_0 = 0 \quad \therefore p_0 = \lambda$. Then

$$U(\lambda) = 0$$

$$G_0(\lambda) = 1$$

$$W(\lambda) = -2$$

$$S_0(\lambda) = - \frac{2\left\{(1 + \frac{p_1}{p_2})e^{2p_1d} - (1 - \frac{p_1}{p_2})\right\}}{(1 + \frac{p_1}{\lambda})(1 + \frac{p_1}{p_2})e^{2p_1d} - (1 - \frac{p_1}{\lambda})(1 - \frac{p_1}{p_2})}$$

$$G_0(\lambda) + S_0(\lambda) = 1 - \frac{2\left\{(1 + \frac{p_1}{p_2})e^{2p_1d} - (1 - \frac{p_1}{p_2})\right\}}{(1 + \frac{p_1}{\lambda})(1 + \frac{p_1}{p_2})e^{2p_1d} - (1 - \frac{p_1}{\lambda})(1 - \frac{p_1}{p_2})}$$

$$= - \frac{(p_1-p_2)(p_1+\lambda)e^{-2p_1d} - (p_1-\lambda)(p_1+p_2)}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1d}} = - \Omega(\lambda) \qquad (2\text{-}85)$$

With $\epsilon_0 = 0$ we can write

$$\Pi_{IIx} = \int_0^\infty e^{-\lambda(z-h)} J_0(\lambda\rho)d\lambda + \int_0^\infty G_0(\lambda)e^{-\lambda(z+h)} J_0(\lambda\rho)d\lambda$$

$$\Pi_{IIz} = -\frac{\partial}{\partial x}\int_0^\infty S_0(\lambda)J_0(\lambda\rho)e^{-\lambda(z+h)}\frac{d\lambda}{\lambda}$$

$$\therefore\quad \nabla\cdot\vec{\Pi}_{II} = \frac{\partial}{\partial x}\Pi_{IIx} + \frac{\partial}{\partial z}\Pi_{IIz}$$

$$= \frac{\partial}{\partial x}\left\{\int_0^\infty e^{-\lambda(z-h)}J_0(\lambda\rho)d\lambda + \int_0^\infty G_0(\lambda)e^{-\lambda(z+h)}J_0(\lambda\rho)d\lambda - \frac{\partial}{\partial z}\int_0^\infty S_0(\lambda)J_0(\lambda\rho)e^{-\lambda(z+h)}\frac{d\lambda}{\lambda}\right\}$$

$$= \frac{\partial}{\partial x}\left\{\int_0^\infty e^{-\lambda(z-h)}J_0(\lambda\rho)d\lambda + \int_0^\infty (G_0(\lambda)+S_0(\lambda))e^{-\lambda(z+h)}J_0(\lambda\rho)d\lambda\right\}$$

$$= \frac{\partial}{\partial x}\left\{\int_0^\infty e^{-\lambda(z-h)}J_0(\lambda\rho)d\lambda - \int_0^\infty \Omega(\lambda)e^{-\lambda(z+h)}J_0(\lambda\rho)d\lambda\right\} \tag{2-86}$$

Equation (2-86) was quoted by Wait (1958).

Case 3. Vertical Electric Dipole

The geometrical configuration for this case is exactly the same as for Case 1 in Figure 1 (p. 23) with the magnetic dipole replaced by an electric dipole. Electric Hertz vectors given in Appendix I are used and the corresponding equations for the electric Hertz vectors which have only z-components are as follows:

$$\Pi_I = \int_0^\infty\left\{\frac{\lambda}{p_0}e^{-p_0(z-h)} + \beta_0(\lambda)e^{-p_0(z+h)}\right\}J_0(\lambda\rho)d\lambda \tag{2-87}$$

$$\Pi_{II} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + \beta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}88)$$

$$\Pi_{III} = \int_0^\infty \left\{ \beta_1(\lambda) e^{p_1 z - p_0 h} + \beta_2(\lambda) e^{-p_1 z - p_0 h} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}89)$$

$$\Pi_{IV} = \int_0^\infty \beta_3(\lambda) e^{p_2 z + (p_2 - p_1)d - p_0 h} J_0(\lambda\rho) d\lambda \qquad (2\text{-}90)$$

It must be noted here that for convenience the electric dipole moment has been taken to be $4\pi\epsilon_0$ coulomb-meter. Since $H_\varphi = -i\omega\epsilon \frac{\partial}{\partial\rho} \Pi_{II}$, $E\rho = \frac{\partial^2}{\partial\rho\partial z} \Pi_{II}$, by arguments parallel to those in Case 1, we can impose the following condition on the Hertz vector instead of $\vec{E}$ and $\vec{H}$.

$$\frac{\partial}{\partial z} \Pi_j = \frac{\partial}{\partial z} \Pi_{j+1} , \quad \epsilon_j \Pi_j = \epsilon_{j+1} \Pi_{j+1} \qquad (2\text{-}91,\ 2\text{-}92)$$

j and $j+1$ denoting adjacent regions.

It is obvious there is a one to one correspondence between the equations (2-87 to 2-92) and the equations (2-13 to 2-20). The former is in fact obtained by replacing the function $F(\lambda)$ by $\beta(\lambda)$ in equations (2-13 to 2-16) and μ by ϵ in (2-19, 2-20). Consequently we can write down the solution for β_0 by replacing μ by ϵ in (2-32):

$$\beta_0(\lambda) = \frac{\lambda}{p_0} \left\{ \frac{(p_1 t_0 + p_0\epsilon_1)(p_1\epsilon_2 - p_2\epsilon_1) e^{-2p_1 d} - (p_1\epsilon_0 - p_0\epsilon_1)(p_1\epsilon_2 + p_2\epsilon_1)}{(p_1\epsilon_0 + p_0\epsilon_1)(p_1\epsilon_2 + p_2\epsilon_1) - (p_1\epsilon_0 - p_0\epsilon_1)(p_1\epsilon_2 - p_2\epsilon_1) e^{-2p_1 d}} \right\}$$

(2-93)

Equation (2-93) is exact and the expression for a homogeneous earth can be obtained by setting $d \longrightarrow \infty$.

$$\beta_0(\lambda) = \frac{\lambda}{p_0} \frac{p_0\epsilon_1 - p_1\epsilon_0}{p_0\epsilon_1 + p_1\epsilon_0}$$

This was given by Sommerfeld with $\mu_0 = \mu_1$ (1949, p. 248)

Case 4. Horizontal Electric Dipole

As in the case of vertical electric dipole treated in the last sub-section, the equations for the electric Hertz vectors, $\vec{\Pi}_e$, boundary conditions and solutions of the equations of a horizontal electric dipole can be obtained from Case 2, provided the orientation of the dipole and the geometric configuration of the earth are represented by Figure 2 (p. 31). We replace the magnetic Hertz vector in Case 2 by electric Hertz vectors given in Appendix I, and replace μ by ϵ in equations (2-40 to 2-43) to obtain boundary conditions for $\vec{\Pi}_e$:

$$\epsilon_j \Pi_{zj} = \epsilon_{j+1} \Pi_{zj+1} \qquad (2\text{-}94)$$

$$\epsilon_j \frac{\partial}{\partial z} \Pi_{xj} = \epsilon_{j+1} \frac{\partial}{\partial z} \Pi_{xj+1} \qquad (2\text{-}95)$$

$$\nabla \cdot \vec{\Pi}_j = \nabla \cdot \vec{\Pi}_{j+1} \qquad (2\text{-}96)$$

$$k_j^2 \Pi_{xj} = k_{j+1}^2 \Pi_{xj+1} \qquad (2\text{-}97)$$

j and $j+1$ denoting adjacent regions.

The x-components of $\vec{\Pi}_e$ in each region are obtained from equations (2-44 to 2-47), arbitrary functions $G_j(\lambda)$ being replaced by $\zeta_j(\lambda)$:

$$\Pi_{Ix} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{-p_0(z-h)} + \zeta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}98)$$

$$\Pi_{IIx} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + \zeta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}99)$$

$$\Pi_{IIIx} = \int_0^\infty \left\{ \zeta_1(\lambda) e^{p_1 z - p_0 h} + \zeta_2(\lambda) e^{-p_1 z - p_0 h} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}100)$$

$$\Pi_{IVx} = \int_0^\infty \left\{ \zeta_3(\lambda) e^{p_2 z + (p_2 - p_1)d - p_1 h} \right\} J_0(\lambda\rho) d\lambda \qquad (2\text{-}101)$$

After applying boundary conditions (2-95, 2-97) and equating the integrands of (2-98 to 2-101), we reduce the resultant equations into the following two equations:

$$\left(\frac{p_1}{p_0} + \frac{\mu_1}{\mu_0}\right) \zeta_1(\lambda) - \left(\frac{p_1}{p_0} - \frac{\mu_1}{\mu_0}\right) \zeta_2(\lambda) = \frac{2\lambda}{p_0} \left(\frac{\epsilon_0}{\epsilon_1}\right) \qquad (2\text{-}102)$$

$$\left(\frac{p_1}{p_2} - \frac{\mu_1}{\mu_2}\right) \zeta_1(\lambda) - \left(\frac{p_1}{p_2} + \frac{\mu_1}{\mu_2}\right) \zeta_2(\lambda) e^{2p_1 d} = 0 \qquad (2\text{-}103)$$

We can write down the expressions for $\zeta_1(\lambda)$ and $\zeta_2(\lambda)$ immediately from (2-56, 2-57)

$$\zeta_1(\lambda) = -\frac{1}{\delta} \frac{2\lambda}{p_0} \left(\frac{\epsilon_0}{\epsilon_1}\right) \left(\frac{p_1}{p_2} + \frac{\mu_1}{\mu_2}\right) e^{2p_1 d} \qquad (2\text{-}104)$$

$$\zeta_2(\lambda) = -\frac{1}{\delta} \frac{2\lambda}{p_0} \left(\frac{\epsilon_0}{\epsilon_1}\right) \left(\frac{p_1}{p_2} - \frac{\mu_1}{\mu_2}\right) \qquad (2\text{-}105)$$

where

$$\delta = \left(\frac{p_1}{p_0} - \frac{\mu_1}{\mu_0}\right)\left(\frac{p_1}{p_2} - \frac{\mu_1}{\mu_2}\right) - \left(\frac{p_1}{p_0} - \frac{\mu_1}{\mu_2}\right)\left(\frac{p_1}{p_2} + \frac{\mu_1}{\mu_2}\right) e^{2p_1 d} \quad (2\text{-}106)$$

and using (2-48), we have

$$\zeta_0(\lambda) = \frac{\lambda}{p_0} - \frac{\epsilon_1 p_1}{\epsilon_0 p_0}\left\{\zeta_1(\lambda) - \zeta_2(\lambda)\right\}$$

or

$$\zeta_0(\lambda) = \frac{\lambda}{p_0}\left\{\frac{(p_1\mu_0+p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1 d} - (p_1\mu_0-p_0\mu_1)(p_1\mu_2+p_2\mu_1)}{(p_1\mu_0+p_0\mu_1)(p_1\mu_2+p_2\mu_1)-(p_1\mu_0-p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1 d}}\right\}$$

(2-107)

The z-component of the electric Hertz vector can be obtained from (2-62 to 2-64), S_j being replaced by η_j.

$$\Pi_{Iz} = \Pi_{IIz} = \cos\varphi \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-p_0(z+h)} \, d\lambda \quad (2\text{-}108)$$

$$\Pi_{IIIz} = \cos\varphi \int_0^\infty J_1(\lambda\rho)\left\{\eta_1(\lambda) e^{p_1 z - p_0 h} + \eta_2(\lambda) e^{-p_1 z - p_0 h}\right\} d\lambda$$

(2-109)

$$\Pi_{IVz} = \cos\varphi \int_0^\infty \eta_3(\lambda) J_1(\lambda\rho) e^{p_2 z + (p_2 - p_1)d - p_0 h} \, d\lambda \quad (2\text{-}110)$$

By analogy with the development in Case 2, the solutions for the first 3 η-functions are:

$$\eta_1 = \frac{1}{\xi(\lambda)}\left\{\frac{\lambda}{p_0}\Phi(\lambda)\left(\frac{\epsilon_1}{\epsilon_2} + \frac{p_1}{p_2}\right)e^{2p_1 d} - \frac{\lambda}{p_0}\varphi(\lambda)\left(\frac{\epsilon_1}{\epsilon_0} - \frac{p_1}{p_0}\right)\right\} \quad (2\text{-}111)$$

$$\eta_2 = \frac{1}{\xi(\lambda)}\left\{\frac{\lambda}{p_2}\varphi(\lambda)\left(\frac{\epsilon_1}{\epsilon_0} + \frac{p_1}{p_2}\right) - \frac{\lambda}{p_0}\Phi(\lambda)\left(\frac{\epsilon_1}{\epsilon_2} - \frac{p_1}{p_2}\right)\right\} \quad (2\text{-}112)$$

$$\eta_0 = \frac{\epsilon_1}{\epsilon_0} \cdot \frac{1}{\xi(\lambda)} \cdot \left\{ \left[\left(\frac{\epsilon_1}{\epsilon_2} + \frac{p_1}{p_2} \right) e^{2p_1 d} - \left(\frac{\epsilon_1}{\epsilon_2} - \frac{p_1}{p_2} \right) \right] \frac{\lambda}{p_0} \Phi(\lambda) - 2 \frac{\lambda}{p_2} \varphi(\lambda) \right\}$$

(2-113)

where

$$\xi(\lambda) = \left(\frac{\epsilon_1}{\epsilon_0} + \frac{p_1}{p_0} \right) \left(\frac{\epsilon_1}{\epsilon_2} + \frac{p_1}{p_2} \right) e^{2p_1 d} - \left(\frac{\epsilon_1}{\epsilon_0} - \frac{p_1}{p_0} \right) \left(\frac{\epsilon_1}{\epsilon_2} - \frac{p_1}{p_2} \right)$$

(2-114)

$$\Phi(\lambda) = (n_{01}^2 - 1)(\zeta_0(\lambda) + \frac{\lambda}{p_0})$$

$$= \frac{2\lambda}{p_0} \frac{(n_{01}^2 - 1) p_0 \mu_1 \left[(p_1\mu_2 - p_2\mu_1) e^{-2p_1 d} + (p_1\mu_2 + p_2\mu_1) \right]}{(p_1\mu_2 + p_0\mu_1)(p_1\mu_2 + p_2\mu_1) - (p_1\mu_0 - p_0\mu_1)(p_1\mu_2 - p_2\mu_1) e^{-2p_1 d}}$$

(2-115)

$$\varphi(\lambda) = \left(\frac{4\lambda p_1 \epsilon_0}{\epsilon_1} \right) \frac{(1 - n_{12}^2)\mu_0\mu_2}{(\mu_0 p_1 - \mu_1 p_0)(p_1\mu_2 - \mu_1 p_2) e^{-2p_1 d} - (\mu_0 p_1 + \mu_1 p_0)(p_1\mu_2 + \mu_1 p_2)}$$

(2-116)

All these expressions are exact. We now check the special case with the horizontal electric dipole on the surface of a 2-layered earth, i.e. $h = 0$, as treated by A. Wolf (1946). He assumed $\epsilon_0 \sim 0$, $\mu_0 = \mu_1 = \mu_2$. $\therefore$ $p_0 = \lambda$.

$$\zeta_0(\lambda) = \frac{(p_1+\lambda)(p_1-p_2) e^{-2p_1 d} - (p_1-\lambda)(p_1+p_2)}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2) e^{-2p_1 d}} \qquad (2\text{-}117)$$

$$\Phi(\lambda) = - (1 + \zeta_0(\lambda))$$

$$\varphi(\lambda) = 0$$

$$\eta_0(\lambda) = - \frac{2\lambda \left\{(p_1+p_2) + (p_1-p_2)e^{-2p_1d}\right\}}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1d}} \tag{2-118}$$

For h = 0, we use (2-98) instead of (2-99).

$$\Pi_{Ix} = \int_0^\infty (1 + \zeta_0)e^{-\lambda z}\ J_0(\lambda\rho)d\lambda$$

$$= \int_0^\infty \frac{2\lambda\left\{(p_1-p_2) + (p_2-p_1)e^{-2p_1d}\right\}}{(p_1+\lambda)(p_1+p_2)-(p_1-\lambda)(p_1-p_2)e^{-2p_1d}}\ e^{-\lambda z}\ J_0(\lambda\rho)d\lambda$$

This is in agreement with Wolf's result.

With these approximations and putting h = 0, (2-108) becomes

$$\Pi_{Iz} = \cos\varphi \int_0^\infty \eta_0(\lambda)J_1(\lambda\rho)e^{-\lambda z}d\lambda$$

$$= -\frac{\partial}{\partial x}\int_0^\infty \eta_0(\lambda)J_0(\lambda\rho)e^{-\lambda z}\ \frac{d\lambda}{\lambda}$$

$$= \frac{\partial}{\partial x}\int_0^\infty \frac{2\left\{(p_1+p_2) + (p_1-p_2)e^{-2p_1d}\right\} J_0(\lambda\rho)e^{-\lambda z}}{(p_1+\lambda)(p_1+p_2)-(p_1-\lambda)(p_1-p_2)e^{-2p_1d}}\ d\lambda$$

This is exactly the negative of Wolf's equation (96), with appropriate sign for z in the exponential. The sign reverses because he used z-downward as positive.

Summary of Results

To conclude this section, it is desirable to summa-

rize the results for each of these four cases that have just been treated. However, since we are only interested in the fields on the surface of the earth, only the components of the Hertz vectors in region I and II are given. Those in the regions inside the earth can be obtained either by referring back to the section directly or by simple substitution. Magnetic Hertz vector is used for the magnetic dipoles and electric Hertz vector for electric dipoles. All the results summarized here are exact and have not appeared in the literature.

Case 1. Vertical Magnetic Dipole

$$\vec{\Pi}_m = \vec{\Pi} = \hat{k}\Pi_z , \quad \Pi_\rho = \Pi_\varphi = 0$$

$$\Pi_I = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{-p_0(z-h)} + F_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad z \geqslant h \tag{2-13}$$

$$\Pi_{II} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + F_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad h \geqslant z \geqslant 0 \tag{2-14}$$

$$F_0(\lambda) = \frac{\lambda}{p_0} \left\{ \frac{(p_1\mu_0+p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1 d} - (p_1\mu_0-p_0\mu_1)(p_1\mu_2+p_2\mu_1)}{(p_1\mu_0+p_0\mu_1)(p_1\mu_2+p_2\mu_1)-(p_1\mu_0-p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1 d}} \right\} \tag{2-32}$$

$p_i = (\lambda^2 - k_i^2)^{1/2}$, $k_i^2 = \omega^2 \mu_i \epsilon_i$,

complex permitivity $\epsilon_i = \epsilon_i + \sqrt{-1}\, \frac{\sigma_i}{\omega}$

Case 2. Horizontal Magnetic Dipole

$$\vec{\Pi}_m = \vec{\Pi} = \hat{i}\Pi_x + \hat{k}\Pi_z \ , \qquad \Pi_y = 0$$

$$\Pi_{Ix} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{-p_0(z-h)} + G_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)\,d\lambda \qquad z \geq h \tag{2-44}$$

$$\Pi_{IIx} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + G_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)\,d\lambda \qquad h \geq z \geq 0 \tag{2-45}$$

$$G_0(\lambda) = \frac{\lambda}{p_0} \left\{ \frac{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d} - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1) - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d}} \right\} \tag{2-58}$$

$$\Pi_{Iz} = \Pi_{IIz} = \cos\varphi \int_0^\infty S_0(\lambda) J_1(\lambda\rho) e^{-p_0(z+h)}\,d\lambda \qquad z \geq 0 \tag{2-62}$$

$$S_0(\lambda) = \frac{\mu_1}{\mu_0} \cdot \frac{1}{D(\lambda)} \left\{ \left[\left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2} \right) e^{2p_1d} - \left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2} \right) \right] \cdot W(\lambda) \cdot \frac{\lambda}{p_0} - U(\lambda) \cdot \frac{2\lambda}{p_2} \right\} \tag{2-83}$$

$$W(\lambda) = (n_{01}^2 - 1)\left(G_0(\lambda) + \frac{\lambda}{p_0}\right) \tag{2-78}$$

$$U(\lambda) = \frac{4\lambda}{p_0} \left(\frac{\mu_0 p_1}{\mu_1 p_2} \right) \frac{(n_{12}^2 - 1)}{\left(\frac{p_1}{p_0} + \frac{\epsilon_1}{\epsilon_0} \right)\left(\frac{p_1}{p_2} + \frac{\epsilon_1}{\epsilon_2} \right) - \left(\frac{p_1}{p_0} - \frac{\epsilon_1}{\epsilon_0} \right)\left(\frac{p_1}{p_2} - \frac{\epsilon_1}{\epsilon_2} \right) e^{-2p_1d}} \tag{2-79}$$

$$D(\lambda) = \left(\frac{\mu_1}{\mu_0} + \frac{p_1}{p_0} \right)\left(\frac{\mu_1}{\mu_2} + \frac{p_1}{p_2} \right) e^{2p_1d} - \left(\frac{\mu_1}{\mu_0} - \frac{p_1}{p_0} \right)\left(\frac{\mu_1}{\mu_2} - \frac{p_1}{p_2} \right) \tag{2-80}$$

Case 3. Vertical Electric Dipole

$$\vec{\Pi}_e = \vec{\Pi} = \hat{k}\Pi_z \ , \qquad \Pi_\rho = \Pi_\varphi = 0$$

$$\Pi_I = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{-p_0(z-h)} + \beta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad z \geqslant h \quad (2\text{-}87)$$

$$\Pi_{II} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + \beta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad h \geqslant z \geqslant 0 \quad (2\text{-}88)$$

$$\beta_0(\lambda) = \frac{\lambda}{p_0} \left\{ \frac{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d} - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1) - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d}} \right\} \quad (2\text{-}93)$$

Case 4. Horizontal Electric Dipole

$$\vec{\Pi}_e = \vec{\Pi} = \hat{i}\Pi_x + \hat{k}\Pi_z \ , \qquad \Pi_y = 0$$

$$\Pi_{Ix} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{-p_0(z-h)} + \zeta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad (2\text{-}98)$$

$$\Pi_{IIx} = \int_0^\infty \left\{ \frac{\lambda}{p_0} e^{p_0(z-h)} + \zeta_0(\lambda) e^{-p_0(z+h)} \right\} J_0(\lambda\rho)d\lambda \qquad (2\text{-}99)$$

$$\zeta_0(\lambda) = \frac{\lambda}{p_0} \left\{ \frac{(p_1\mu_0+p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1d} - (p_1\mu_0-p_0\mu_1)(p_1\mu_2+p_2\mu_1)}{(p_1\mu_0+p_0\mu_1)(p_1\mu_2+p_2\mu_1) - (p_1\mu_0-p_0\mu_1)(p_1\mu_2-p_2\mu_1)e^{-2p_1d}} \right\} \quad (2\text{-}107)$$

$$\Pi_{Iz} = \Pi_{IIz} = \cos\varphi \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-p_0(z+h)} d\lambda \qquad (2\text{-}108)$$

$$\eta_0(\lambda) = \frac{\epsilon_1}{\epsilon_0} \cdot \frac{1}{\xi(\lambda)} \left\{ \left[\left(\frac{\epsilon_1}{\epsilon_2} + \frac{p_1}{p_2} \right) e^{2p_1 d} - \left(\frac{\epsilon_1}{\epsilon_2} - \frac{p_1}{p_2} \right) \right] \cdot \Phi(\lambda) \cdot \frac{\lambda}{p_0} - \varphi(\lambda) \cdot \frac{2\lambda}{p_2} \right\} \tag{2-113}$$

$$\Phi(\lambda) = (n_{01}^2 - 1)(\zeta_0(\lambda) + \frac{\lambda}{p_0})$$

$$\varphi(\lambda) = \frac{4\lambda p_1 \epsilon_0}{\epsilon_1} \cdot \frac{(1 - n_{12}^2)\mu_0\mu_2}{(\mu_0 p_1 - \mu_1 p_0)(p_1\mu_2 - \mu_1 p_2)e^{-2p_1 d} - (\mu_0 p_1 \ \mu_1 p_0)(p_1 \mu_2 \ \mu_1 p_2)} \tag{2-117}$$

$$\xi(\lambda) = \left(\frac{\epsilon_1}{\epsilon_0} + \frac{p_1}{p_0} \right) \left(\frac{\epsilon_1}{\epsilon_2} + \frac{p_1}{p_2} \right) e^{2p_1 d} - \left(\frac{\epsilon_1}{\epsilon_0} - \frac{p_1}{p_0} \right) \left(\frac{\epsilon_1}{\epsilon_2} - \frac{p_1}{p_2} \right) \tag{2-114}$$

2.2 Explicit Field Components

In the last section the Hertz vectors in each case have been formulated and their solutions have been obtained in their exact form. It is now necessary to derive the electric and magnetic field components from them. The complicated expressions will be simplified without distorting the fields for practical purposes.

The permeability of the air and both layers of the earth are considered equal to μ_0, the free space value. The whole space is thereby treated as magnetically uniform. The conductivity of the air σ_0 is taken to be zero and its permitivity ϵ_0 is assigned the value of free space. ϵ_0 appears most frequently in p_0 and

$$p_0 = (\lambda^2 - \omega^2\mu_0\epsilon_0)^{1/2} \simeq \lambda(1 - \frac{1}{2}\frac{\omega^2\mu_0\epsilon_0}{\lambda^2}) . \qquad (2\text{-}119)$$

λ being the variable of integration whose value ranges from 0 to ∞. Therefore we can set $p_0 = \lambda$ in the integrand under one condition, i.e. when the contribution of the part of integration at $\lambda^2 \lesssim \frac{\omega^2\mu_0\epsilon_0}{2}$ is negligible to the entire integral. This will be further discussed in the next chapter. It is also obvious that we should use

$$(\lambda - p_0) = \frac{1}{2}\frac{\omega^2\mu_0\epsilon_0}{\lambda} \qquad (2\text{-}120)$$

wherever it occurs. This will be set equal to zero only when it is compared with some large quantity, otherwise it will be retained.

Each case will be treated separately again so that the Hertz vectors will be found by reference to the last chapter.

Case 1. Vertical Magnetic Dipole

(I-23) and (I-24) give the electromagnetic fields in terms of the magnetic Hertz vector. In this case

$$E_z = E_\rho = H_\varphi = 0$$

$$E_\varphi = i\omega\mu_0 \frac{\partial}{\partial\rho}\Pi , \quad H_\rho = \frac{\partial^2}{\partial\rho\partial z}\Pi , \quad H_z = k_0^2\Pi + \frac{\partial^2}{\partial z^2}\Pi$$

where Π is given by (2-14) and (2-32) which is further reduced to (2-33) after approximations have been applied. We have

$$E_\varphi = -i\omega\mu_0 \int_0^\infty \left\{ e^{\lambda(z-h)} + \chi(\lambda)e^{-\lambda(z+h)} \right\} (-\lambda)J_1(\lambda\rho)d\lambda$$

at $z = 0$

$$E_\varphi = i\omega\mu_0 \int_0^\infty \lambda(1 + \chi(\lambda))J_1(\lambda\rho)e^{-\lambda h}\, d\lambda \tag{2-121}$$

where

$$\chi(\lambda) = \frac{(p_1+\lambda)(p_1-p_2)e^{-2p_1 d} - (p_1-\lambda)(p_1+p_2)}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1 d}} \tag{2-122}$$

$F_0(\lambda)$ given by (2-33) is replaced by $\chi(\lambda)$ to avoid confusion because (2-122) will appear very frequently in the rest of this section.

$$H_\rho = \int_0^\infty \lambda^2 \left\{ \chi(\lambda) - 1 \right\} J_1(\lambda\rho)e^{-\lambda h}\, d\lambda \tag{2-123}$$

$$H_z = k_0^2 \int_0^\infty (1 + \chi(\lambda))J_0(\lambda\rho)e^{-\lambda h}\, d\lambda + \int_0^\infty p_0^2(1 + \chi(\lambda))J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$= \int_0^\infty (p_0^2 + k_0^2)(1 + \chi(\lambda))J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$= \int_0^\infty \lambda^2(1 + \chi(\lambda))J_0(\lambda\rho)e^{-\lambda h}\, d\lambda \tag{2-124}$$

since $p_0^2 = \lambda^2 - k_0^2$.

Case 2. Horizontal Magnetic Dipole

For this case, the following are the E and H components in the Cartesian coordinates. The Hertz vector is given by (2-45) and (2-62).

$$H_x = k_0^2 \, \Pi_x \cdot \frac{\partial}{\partial x} (\mathrm{div}\, \vec{\Pi}) \qquad E_x = i\omega\mu_0 \frac{\partial}{\partial y} \Pi_z$$

$$H_y = \frac{\partial}{\partial y} (\mathrm{div}\, \vec{\Pi}) \qquad E_y = i\omega\mu_0 \left(\frac{\partial}{\partial x} \Pi_x - \frac{\partial}{\partial x} \Pi_z\right)$$

$$H_z = k_0^2 \, \Pi_z + \frac{\partial}{\partial z} (\mathrm{div}\, \vec{\Pi}) \qquad E_z = - i\omega\mu_0 \frac{\partial}{\partial y} \Pi_x$$

After the application of approximations mentioned at the beginning of the section one has

$$\mathrm{div}\, \vec{\Pi} = \frac{\partial}{\partial x} \left\{ \int_0^\infty J_0(\lambda\rho) e^{+p_0(z-h)} \, d\lambda - \int_0^\infty \chi(\lambda) J_0(\lambda\rho) e^{-p_0(z+h)} \, d\lambda \right\}$$

$$= \frac{x}{\rho} \left\{ \int_0^\infty \lambda\chi(\lambda) J_1(\lambda\rho) e^{-p_0(z-h)} \, d\lambda - \int_0^\infty \lambda J_1(\lambda\rho) e^{p_0(z+h)} \, d\lambda \right\} \tag{2-125}$$

where $z < h$. (cf. 2-86).

and $\Pi_x = 2 \int_0^\infty e^{-\lambda h} \, J_0(\lambda\rho) d\lambda$ at $z = 0$.

$$\text{Since } \frac{\partial}{\partial x} \left(\frac{x}{\rho} f(\rho) \right) = \left(\frac{1}{\rho} - \frac{x^2}{\rho^3} \right) f(\rho) + \frac{x^2}{\rho^2} \frac{\partial}{\partial \rho} f(\rho)$$

$$\frac{\partial}{\partial y} \left(\frac{x}{\rho} f(\rho) \right) = - \frac{xy}{\rho^3} f(\rho) + \frac{xy}{\rho^2} \frac{\partial}{\partial \rho} f(\rho)$$

$$\text{and} \quad \frac{\partial}{\partial \rho} J_1(\lambda\rho) = \lambda J_0(\lambda\rho) - \frac{1}{\rho} J_1(\lambda\rho)$$

we have, at $z = 0$

$$H_x = 2k_0^2 \int_0^\infty e^{-\lambda h} \, J_0(\lambda\rho) d\lambda + \frac{1}{\rho} \left(1 - \frac{2x^2}{\rho^2}\right) \int_0^\infty \lambda(\chi(\lambda)-1) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$+ \frac{x^2}{\rho^2} \int_0^\infty \lambda^2(\chi(\lambda) - 1)J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$\simeq \frac{1}{\rho}\left(1 - \frac{2x^2}{\rho^2}\right) \int_0^\infty \lambda(\chi(\lambda) - 1)J_1(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$+ \frac{x^2}{\rho^2} \int_0^\infty \lambda^2(\chi(\lambda) - 1)J_0(\lambda\rho)e^{-\lambda h}\, d\lambda \qquad (2\text{-}126)$$

$$H_y = -\frac{xy}{\rho^3} \int_0^\infty \lambda(\chi(\lambda) - 1)J_1(\lambda\rho)e^{-\lambda h}\, d\lambda + \frac{xy}{\rho^2}\frac{\partial}{\partial\rho}\int_0^\infty(\chi(\lambda)-1)J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$= -\frac{2xy}{\rho^3}\int_0^\infty \lambda(\chi(\lambda)-1)J_1(\lambda\rho)e^{-\lambda h}\, d\lambda + \frac{xy}{\rho^2}\int_0^\infty \lambda^2(\chi(\lambda)-1)J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$(2\text{-}127)$$

$$H_z = k_0^2 \cos\varphi \int_0^\infty (1+\chi(\lambda))J_1(\lambda\rho)e^{-\lambda h}\, d\lambda - \frac{x}{\rho}\int_0^\infty \lambda^2(\chi(\lambda)+1)J_1(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$\simeq -\cos\varphi \int_0^\infty \lambda^2(1+\chi(\lambda))J_1(\lambda\rho)e^{-\lambda h}\, d\lambda \qquad (2\text{-}128)$$

$$E_x = i\omega\mu_0\left\{-\frac{xy}{\rho^3}\int_0^\infty (1+\chi(\lambda))J_1)\lambda\rho)e^{-\lambda h}\, d\lambda + \frac{xy}{\rho^2}\int_0^\infty (1+\chi(\lambda))\right.$$

$$\left.\cdot(\lambda J_0(\lambda\rho) - \frac{1}{\rho} J_1(\lambda\rho))e^{-\lambda h}\, d\lambda\right\}$$

$$= i\omega\mu_0\left\{\frac{xy}{\rho^2}\int_0^\infty \lambda(1+\chi(\lambda))J_0(\lambda\rho)e^{-\lambda h}\, d\lambda - \frac{2xy}{\rho^3}\int_0^\infty(1+\chi(\lambda))J_1(\lambda\rho)e^{-\lambda h}\, d\lambda\right\}$$

$$(2\text{-}129)$$

$$E_y = i\omega\mu_0 \left\{ \int_0^\infty p_0\left(\frac{\lambda}{p_0} - G_0(\lambda)\right) J_0(\lambda\rho) e^{-\lambda h} \, d\lambda \right.$$

$$\left. - \frac{\partial}{\partial x} \left(\frac{x}{\rho} \int_0^\infty S_0(\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \right) \right\}$$

$$\simeq - i\omega\mu_0 \left\{ \frac{x^2}{\rho^2} \int_0^\infty \lambda S_0(\lambda) J_0(\lambda\rho) e^{-\lambda h} \, d\lambda \right.$$

$$\left. + \left(\frac{1}{\rho} - \frac{2x^2}{\rho^3}\right) \int_0^\infty S_0(\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \right\}$$

$$\simeq i\omega\mu_0 \left\{ \frac{x^2}{\rho^2} \int_0^\infty \lambda(1+\chi(\lambda)) J_0(\lambda\rho) e^{-\lambda h} \, d\lambda + \left(\frac{1}{\rho} - \frac{2x^2}{\rho^3}\right) \right.$$

$$\left. \int_0^\infty (1+\chi(\lambda)) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \right\} \qquad (2\text{-}130)$$

since $\left\{ \frac{\lambda}{p_0} - G_0(\lambda) \right\} = -2f(\epsilon_0, \lambda)$ (Appendix IV)

and $S_0(\lambda) = -(1 + \chi(\lambda))$.

$$E_z = i\omega\mu_0 \frac{2y}{\rho} \int_0^\infty \lambda J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \qquad (2\text{-}131)$$

<u>Case 3. Vertical Electric Dipole</u>

For this case the electric Hertz vector is given by (2-88)

$$\vec{\Pi} = \hat{k}\Pi_{II}, \qquad \Pi_\rho = \Pi_\varphi = 0$$

and $H_z = H_\rho = E_\varphi = 0$,

$$H_\varphi = - i\omega\epsilon_0 \frac{\partial}{\partial\rho} \Pi \ , \qquad E_\rho = \frac{\partial^2}{\partial\rho\partial z} \Pi \ , \qquad E_z = k_0^2 \Pi + \frac{\partial^2}{\partial z^2} \Pi$$

$$H_\varphi = -i\omega\epsilon_0 \int_0^\infty \left\{ \frac{\lambda}{p_0} + \beta_0(\lambda) \right\} (-\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$\simeq i\omega\epsilon_0 \, 2 \int_0^\infty \lambda J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \tag{2-132}$$

since $\frac{\lambda}{p_0} + \beta_0(\lambda) \simeq 2$

$$E_z \simeq k_0^2 \, 2 \int_0^\infty J_o(\lambda\rho) e^{-\lambda h} \, d\lambda + 2 \int_0^\infty (\lambda^2 - \tfrac{1}{2} k_0^2) J_0(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$= k_0^2 \int_0^\infty J_0(\lambda\rho) e^{-\lambda h} \, d\lambda + 2 \int_0^\infty \lambda^2 J_0(\lambda\rho) e^{-\lambda h} \, d\lambda \tag{2-133}$$

$$E_\rho = \int_0^\infty p_0 \left\{ \frac{\lambda}{p_0} - \beta_0(\lambda) \right\} (-\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

since $\beta_0(\lambda) = G_0(\lambda)$, $\therefore \left\{ \frac{\lambda}{p_0} - \beta_0(\lambda) \right\} = -2f(\epsilon_0, \lambda)$ (Appendix IV)

$$E_\rho = 2 \int_0^\infty \lambda^2 f(\epsilon_0, \lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \tag{2-134}$$

Case 4. Horizontal Electric Dipole

For this case, the electric Hertz vector has x and z cartesian components only, i.e.

$$\vec{\Pi} = \hat{i}\Pi_x + \hat{k}\Pi_z \,, \qquad \Pi_y = 0$$

Π_x and Π_z being given by (2-99) and (2-108). The field components are

$$E_x = k_0^2\Pi_x + \frac{\partial}{\partial x}(\mathrm{div}\,\vec{\Pi}) \,, \qquad H_x = -\,i\omega\epsilon_0 \frac{\partial}{\partial y}\Pi_z$$

$$E_y = \frac{\partial}{\partial y}(\mathrm{div}\,\vec{\Pi}) \,, \qquad H_y = i\omega\epsilon_0\left(\frac{\partial}{\partial x}\Pi_z - \frac{\partial}{\partial z}\Pi_x\right)$$

$$E_z = k_0^2\,\Pi_z + \frac{\partial}{\partial z}(\mathrm{div}\,\vec{\Pi}), \qquad H_z = i\omega\epsilon_0 \frac{\partial}{\partial y}\Pi_x$$

where $\quad \mathrm{div}\,\vec{\Pi} = \frac{\partial}{\partial x}\Pi_x + \frac{\partial}{\partial z}\Pi_z$

$$= \frac{\partial}{\partial x}\int_0^\infty \left\{\frac{\lambda}{p_0}\, e^{+p_0(z-h)} + \zeta_0(\lambda)e^{-p_0(z+h)} + \frac{p_0}{\lambda}\,\eta_0(\lambda)e^{-p_0(z+h)}\right\} J_0(\lambda\rho)\,d\lambda$$

$$= \frac{\partial}{\partial x}\int_0^\infty \left\{\frac{\lambda}{p_0}\, e^{p_0(z-h)} + \zeta_0(\lambda)e^{-p_0(z+h)} + \frac{p_0}{\lambda}\left[-\frac{\lambda}{p_0}(1+\zeta_0(\lambda))\right] e^{-p_0(z+h)}\right\} J_0(\lambda\rho)\,d\lambda$$

$$= \frac{\partial}{\partial x}\int_0^\infty \left\{\frac{\lambda}{p_0}\, e^{p_0(z-h)} - e^{-p_0(z+h)}\right\} J_0(\lambda\rho)\,d\lambda$$

$$= \frac{x}{\rho}\int_0^\infty \lambda\left\{e^{-p_0(z+h)} - \frac{\lambda}{p_0}\, e^{p_0(z-h)}\right\} J_1(\lambda\rho)\,d\lambda \qquad (2\text{-}135)$$

$\eta_0(\lambda) = -\frac{\lambda}{p_0}(1 + \zeta_0(\lambda))$ subject to ϵ_0 being small (cf. 2-117, 2-118). Now we can immediately write down the field components at $z = 0$.

$$E_x = k_0^2 \int_0^\infty \left(\frac{\lambda}{p_0} + \zeta_0(\lambda)\right) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda + \frac{\partial}{\partial x}\left\{\frac{x}{\rho}\int_0^\infty \lambda(1-\frac{\lambda}{p_0}) J_1(\lambda\rho)e^{-\lambda h}\, d\lambda\right\}$$

$$= k_0^2 \int_0^\infty \left(\frac{\lambda}{p_0} + \zeta_0(\lambda)\right) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda + \left(\frac{1}{\rho} - \frac{2x^2}{\rho^3}\right)\int_0^\infty \lambda(1-\frac{\lambda}{p_0})\times$$

$$J_1(\lambda\rho)e^{-\lambda h}\, d\lambda + \frac{x^2}{\rho^2}\int_0^\infty \lambda^2(1-\frac{\lambda}{p_0}) J_0(\lambda\rho)e^{-\lambda h}\, d\lambda$$

Applying the approximations

$$\zeta_0(\lambda) = \chi(\lambda)$$

$$\left(1 - \frac{\lambda}{p_0}\right) = -\frac{k_0^2}{2\lambda^2}$$

$$E_x = k_0^2 \int_0^\infty \left(1+\chi(\lambda)\right) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda + \left(\frac{1}{\rho} - \frac{2x^2}{\rho^3}\right)\int_0^\infty (-\frac{k_0^2}{2\lambda}) J_1(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$+ \frac{x^2}{\rho^2}\int_0^\infty (-\frac{k_0^2}{2}) J_0(\lambda\rho)e^{-\lambda h}\, d\lambda \qquad (2\text{-}136)$$

$$E_y = \frac{\partial}{\partial y}\left\{\frac{x}{\rho}\int_0^\infty \lambda(1-\frac{\lambda}{p_0}) J_1(\lambda\rho)e^{-\lambda h}\, d\lambda\right\}$$

$$\simeq (-\frac{xy}{\rho^3})\int_0^\infty (-\frac{k_0^2}{2\lambda}) J_1(\lambda\rho)e^{-\lambda h}\, d\lambda + \frac{xy}{\rho^2}\int_0^\infty (-\frac{k_0^2}{2\lambda})$$

$$\left(\lambda J_0(\lambda\rho) - \frac{1}{\rho} J_1(\lambda\rho)\right) e^{-\lambda h}\, d\lambda$$

$$= k_0^2 \frac{xy}{\rho^3} \int_0^\infty J_1(\lambda\rho) e^{-\lambda h} \frac{d\lambda}{\lambda} - \frac{k_0^2}{2} \frac{xy}{\rho^2} \int_0^\infty J_0(\lambda\rho) e^{-\lambda h} \, d\lambda \qquad (2\text{-}137)$$

$$E_z = k_0^2 \cos\varphi \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda + \frac{x}{\rho} \int_0^\infty \lambda(-p_0 - \lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$= -k_0^2 \cos\varphi \int_0^\infty (1 + \chi(\lambda)) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda - \frac{2x}{\rho} \int_0^\infty \lambda^2 J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$+ \frac{1}{2} k_0^2 \frac{x}{\rho} \int_0^\infty J_1(\lambda\rho) e^{-\lambda h} \, d\lambda$$

$$\simeq -k_0^2 \cos\varphi \int_0^\infty \left(\frac{1}{2} + \chi(\lambda)\right) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda - \frac{2x}{\rho} \int_0^\infty \lambda^2 J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \qquad (2\text{-}138)$$

$$H_x = -i\omega\epsilon_0 \frac{\partial}{\partial y} \left(\frac{x}{\rho} \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda \right)$$

$$= -i\omega\epsilon_0 \left\{ -\frac{xy}{\rho^3} \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda + \frac{xy}{\rho^2} \int_0^\infty \eta_0(\lambda) \Big(\lambda J_0(\lambda\rho) \right.$$

$$\left. - \frac{1}{\rho} J_1(\lambda\rho) \Big) e^{-\lambda h} \, d\lambda \right\}$$

$$\simeq +i\omega\epsilon_0 \left\{ -\frac{2xy}{\rho^3} \int_0^\infty (1 + \chi(\lambda)) J_1(\lambda\rho) e^{-\lambda h} \, d\lambda + \frac{xy}{\rho^2} \int_0^\infty (1 + \chi(\lambda)) \right.$$

$$\left. \lambda J_0(\lambda\rho) e^{-\lambda h} \, d\lambda \right\} \qquad (2\text{-}139)$$

$$H_y = i\omega\epsilon_0 \left\{ \frac{\partial}{\partial x}\left(\frac{x}{\rho} \int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda \right) \right.$$

$$\left. - \int_0^\infty p_0 \left(\frac{\lambda}{p_0} - \zeta_0(\lambda) \right) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda \right\}$$

$$\simeq i\omega\epsilon_0 \left\{ - \int_0^\infty \lambda(1 - \chi(\lambda)) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda + \left(\frac{1}{\rho} - \frac{x^2}{\rho^3} \right) \right.$$

$$\int_0^\infty \eta_0(\lambda) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda + \frac{x^2}{\rho^2} \int_0^\infty \eta_0(\lambda) \left(\lambda J_0(\lambda\rho) \right.$$

$$\left. \left. - \frac{1}{\rho} J_1(\lambda\rho) \right) e^{-\lambda h}\, d\lambda \right\}$$

$$\simeq i\omega\epsilon_0 \left\{ - \left(1 + \frac{x^2}{\rho^2} \right) \int_0^\infty \lambda J_0(\lambda\rho) e^{-\lambda h}\, d\lambda + \left(1 - \frac{x^2}{\rho^2} \right) \cdot \right.$$

$$\cdot \int_0^\infty \lambda \chi(\lambda) J_0(\lambda\rho) e^{-\lambda h}\, d\lambda - \left(\frac{1}{\rho} - \frac{2x^2}{\rho^3} \right) \cdot$$

$$\left. \cdot \int_0^\infty \left(1 + \chi(\lambda) \right) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda \right\} \qquad (2\text{-}140)$$

$$H_z = i\omega\epsilon_0 \frac{y}{\rho} \left\{ \int_0^\infty \left(\frac{\lambda}{p_0} + \zeta_0(\lambda) \right) (-\lambda) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda \right\}$$

$$\simeq - i\omega\epsilon_0 \frac{y}{\rho} \int_0^\infty \lambda \left(1 + \chi(\lambda) \right) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda \qquad (2\text{-}141)$$

Summary

The field components on the surface of the earth derived in this section are summarized here. Though the solutions of the Hertz vectors given in section 2.1 are exact, the field components derived from them are based on the following approximations: $\sigma_0 = 0$, $\mu_0 = \mu_1 = \mu_2$, $\epsilon_1 << \frac{\sigma_1}{\omega}$, $\epsilon_2 << \frac{\sigma_2}{\omega}$. Therefore both ϵ_1 and ϵ_2 are neglected. ϵ_0 is retained only when it is not compared with any other larger quantities, otherwise it is neglected. However, for high frequencies the approximations may not be valid. For example, E_z for the vertical electric dipole is given by (2-133) or

$$E_z = 2N(2,0) + k_0^2\, N(0,0). \qquad \text{(See below for}$$

definition of $N(\mu, \nu)$)

$N(2,0)$ is of the order $(h)^{-3}$ and $N(0,0)$ of the order of h^{-1}, $k_0^2 \sim 4 \times 10^{-16}/T^2$.

$$\frac{k_0^2\, N(0,0)}{N(2,0)} \sim h^2 \times \frac{4 \times 10^{-16}}{T^2}$$

In this study $h \sim 10^5$ m.

$$\frac{4h^2 \times 10^{-16}}{T^2} = \frac{4 \times 10^{-6}}{T^2}$$

If $T \sim 10^{-3}$ sec, or $f = 1000$ c/sec, the second term is not negligible compared with the first. The following field components are valid for the work in this thesis. For applications with different h and different range of frequencies, the original text in the previous pages must be consulted.

The dipole moment of the magnetic dipole is 4π amp-m^2, and that of the electric dipole is $4\pi\epsilon_0$ coulomb-m. The following list of symbols are used in the summary:

$$N(\mu,\nu) = \int_0^\infty \lambda^\mu J_\nu(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$T(\mu,\nu) = \int_0^\infty \lambda^\mu\, \chi(\lambda)J_\nu(\lambda\rho)e^{-\lambda h}\, d\lambda$$

$$\tau(2,1) = \int_0^\infty \lambda^2 f(\lambda)J_1(\lambda\rho)e^{-\lambda h}\, d\lambda.$$

$\mu = -1,\ 0,\ 1,\ 2$

$\nu = 0,\ 1$

h = height of dipole

ρ = radial distance from the origin

$J_\nu(\lambda\rho)$ = Bessel function of 1st kind, and order ν.

$$\chi(\lambda) = \frac{(p_1+\lambda)(p_1-p_2)e^{-2p_1 d} - (p_1-\lambda)(p_1+p_2)}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1 d}}$$

$$f(\lambda) = \left(\frac{\omega\epsilon_0 p_1}{i\sigma_1\lambda}\right)\frac{\left(p_1\frac{\sigma_2}{\sigma_1} - p_2\right)e^{-2p_1 d} - \left(p_1\frac{\sigma_2}{\sigma_1} + p_2\right)}{\left(p_1\frac{\sigma_2}{\sigma_1} + p_2\right) + \left(p_1\frac{\sigma_2}{\sigma_1} - p_2\right)e^{-2p_1 d}}$$

$$p_j = (\lambda^2 - k_j^2)^{1/2}$$

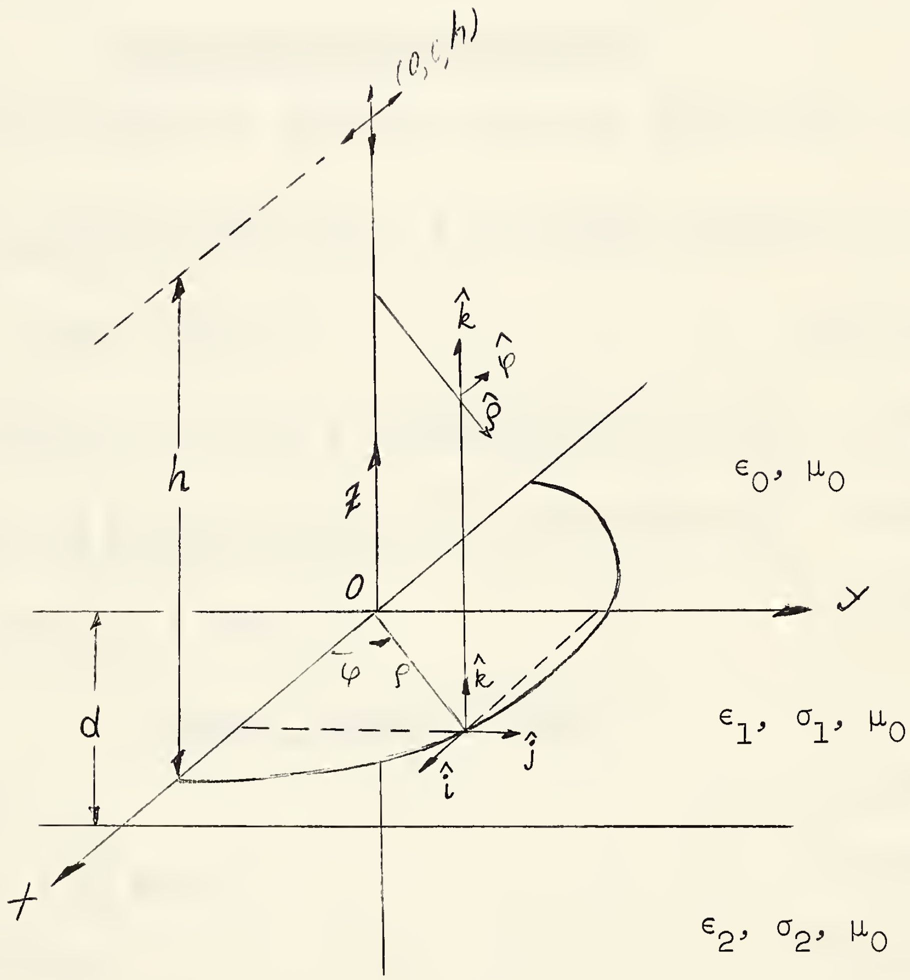
$$k_j^2 = \omega^2\mu_0\left(\epsilon_j + \frac{i\sigma_j}{\omega}\right)$$

ϵ_j , μ_0 , σ_j are permittivity, permeability and conductivity.

d = thickness of upper layer.

$\frac{x}{\rho} = \cos\varphi$

$\frac{y}{\rho} = \sin\varphi$



Coordinate Systems

Vertical Magnetic Dipole

$$E_\varphi = - i\omega\mu_0 \left\{ N(1,1) + T(1,1) \right\} \tag{2-142}$$

$$H_\rho = - N(2,1) + T(2,1) \tag{2-143}$$

$$H_z = N(2,0) + T(2,0) \tag{2-144}$$

$$E_\rho = E_z = H_\varphi = 0$$

Horizontal Magnetic Dipole

$$E_x = i\omega\mu_0 \frac{1}{2} \sin 2\varphi \left\{ N(1,0) - \frac{2}{\rho} N(0,1) + T(1,0) - \frac{2}{\rho} T(0,1) \right\} \tag{2-145}$$

$$E_y = i\omega\mu_0 \left\{ \cos^2\varphi \left[N(1,0)+T(1,0) \right] - \frac{1}{\rho} \cos 2\varphi \left[N(0,1)+T(0,1) \right] \right\} \tag{2-146}$$

$$E_z = i\omega\mu_0 \cdot 2 \sin\varphi \cdot N(1,1) \tag{2-147}$$

$$H_x = \frac{1}{\rho} \cos 2\varphi \left\{ N(1,1)-T(1,1) \right\} + \cos^2\varphi \left\{ -N(2,0)+T(2,0) \right\} \tag{2-148}$$

$$H_y = - \frac{1}{2} \sin 2\varphi \left\{ \frac{2}{\rho} \left[-N(1,1)+T(1,1) \right] - N(2,0)+T(2,0) \right\} \tag{2-149}$$

$$H_z = - \cos\varphi \left\{ N(2,1) + T(2,1) \right\} \tag{2-150}$$

Vertical Electric Dipole

$$E_\rho = 2\tau(2,1) \tag{2-151}$$

$$E_z = 2N(2,0) + k_0^2 N(0,0) \tag{2-152}$$

$$H_\varphi = i\omega\epsilon_0 \, 2N(1,1) \tag{2-153}$$

$$H_\rho = H_z = E_\varphi = 0$$

Horizontal Electric Dipole

$$E_x = k_0^2 \left\{ (1 - \frac{1}{2} \cos^2\varphi) N(0,0) + T(0,0) + \frac{1}{2\rho} \cos 2\varphi \, N(-1,1) \right\} \tag{2-154}$$

$$E_y = k_0^2 \cdot \frac{1}{2} \sin 2\varphi \left\{ \frac{1}{\rho} N(-1,1) - \frac{1}{2} N(0,0) \right\} \qquad (2\text{-}155)$$

$$E_z = - 2 \cos\varphi \, N(2,1) - k_0^2 \cos\varphi \left\{ \frac{1}{2} N(0,1) + T(0,1) \right\} \qquad (2\text{-}156)$$

$$H_x = i\omega\epsilon_0 \cdot \frac{1}{2} \sin 2\varphi \left\{ - \frac{2}{\rho} \left[N(0,1)+T(0,1) \right] + N(1,0)+T(1,0) \right\} \qquad (2\text{-}157)$$

$$H_y = i\omega\epsilon_0 \left\{ -(1+\cos^2\varphi)N(1,0) + \sin^2\varphi T(1,0) + \frac{1}{\rho} \cos 2\varphi \left[N(0,1)+T(0,1) \right] \right\} \qquad (2\text{-}158)$$

$$H_z = - i\omega\epsilon_0 \sin\varphi \left\{ N(1,1) + T(1,1) \right\} \qquad (2\text{-}159)$$

III. ASYMPTOTIC APPROXIMATION AND NUMERICAL COMPUTATION OF THE COMPLEX INTEGRALS

In order to compute the field components in each case, we have to evaluate three types of integrals as shown on page 64. They shall be referred to as N, T and τ, and the complex functions under the integral sign as f and χ. By using the well-known results

$$N(0,0) = \int_0^\infty J_0(\lambda\rho)e^{-\lambda h}\, d\lambda = \frac{1}{(\rho^2+h^2)^{1/2}} \tag{3-1}$$

$$N(0,1) = \int_0^\infty J_1(\lambda\rho)e^{-\lambda h}\, d\lambda = \frac{(\rho^2+h^2)^{1/2} - h}{\rho(\rho^2+h^2)^{1/2}} \tag{3-2}$$

then $N(\mu,\nu)$ with $\mu > 0$ can be evaluated as follows:

$$N(\mu,0) = (-1)^\mu \frac{\partial^\mu}{\partial h^\mu}\int_0^\infty J_0(\lambda\rho)e^{-\lambda h}\, d\lambda = (-1)^\mu \frac{\partial^\mu}{\partial h^\mu}\left[\frac{1}{(\rho^2+h^2)^{1/2}}\right] \tag{3-3}$$

$$N(1,1) = -\frac{\partial}{\partial\rho}\int_0^\infty J_0(\lambda\rho)e^{-\lambda h}\, d\lambda = -\frac{\partial}{\partial\rho}\left[\frac{1}{(\rho^2+h^2)^{1/2}}\right] \tag{3-4}$$

$$N(\mu+1,1) = (-1)^{\mu+1}\frac{\partial^\mu}{\partial h^\mu}\left(\frac{\partial}{\partial\rho}\frac{1}{(\rho^2+h^2)^{1/2}}\right) = \left(-\frac{\partial}{\partial\rho}\right)N(\mu,0), \qquad \mu \geqslant 1 \tag{3-5}$$

Equation (3-5) relates $N(\mu,1)$ to $N(\mu,0)$. $N(\mu,0)$ and $N(\mu,1)$ are given in Appendix V.

3.1 Asymptotic Approximation of $T(\mu,\nu)$

$T(\mu,\nu)$ differs from $N(\mu,\nu)$ by the complex function $\chi(\lambda)$. If $\chi(\lambda)$ is expanded in a power series of the form

$$\chi(\lambda) = \sum_{\ell=0}^{\infty} a_\ell \lambda^\ell \tag{3-6}$$

then $T(\mu,\nu)$ can be written as

$$T(\mu,\nu) = \sum_{\ell=0}^{\infty} a_\ell N(\mu+\ell,\nu) \tag{3-7}$$

and thus evaluated as a power series.

(3-6) can be achieved by Taylor's expansion about 0 in which a_ℓ is given by

$$a_\ell = \frac{1}{\ell!}\left[\frac{d^\ell}{d\lambda^\ell}\chi(\lambda)\right]_{\lambda=0} \tag{3-8}$$

provided that all derivatives of $\chi(\lambda)$ exist at $\lambda = 0$ (Wait, 1958). Since $\chi(\lambda)$ is a very complicated function, finding its high order derivatives is an extremely laborious process. Three of them are given in Appendix VI and the corresponding Taylor coefficients are given below.

$$a_0 = -1$$

$$a_1 = -\frac{2i}{k_1} L$$

$$a_2 = \frac{2L^2}{k_1^2}$$

$$a_3 = i\,\frac{n^2}{k_1^3}\left\{1 - nL - L^2 + 2nL^3\right\} - \frac{2(1-n)de^{\theta}}{k_1^2\left\{(1+n)-(1-n)e^{\theta}\right\}}$$

where $L = \dfrac{(1+n)+(1-n)e^{\theta}}{(1+n)-(1-n)e^{\theta}}$, $\quad n = \dfrac{k_2}{k_1}$, $\quad \theta = -\,i2k_1 d$.

Putting $\mu = 2$, $\nu = 0$ in (3-7), we have

$$T(2,0) = \sum_{\ell=0}^{\infty} a_{\ell}\, N(2+\ell,0)$$

$$= -\,N(2,0) - i\,\frac{2}{k_1}\,L \cdot N(3,0) + \frac{2L^2}{k_1^2}\,N(4,0)$$

$$+ \frac{1}{k_1^3}\left\{ in^2\left[1-nL-L^2+2nL^3\right] - \frac{2(1-n)k_1de^{\theta}}{(1-n)-(1-n)e^{\theta}}\right\} N(5,0)$$

$$+ \ldots$$

$$= \left\{\frac{1}{Q^{3/2}} - \frac{3h^2}{Q^{5/2}}\right\} + i\,\frac{6L}{k_1}\left\{\frac{3h}{Q^{5/2}} - \frac{5h^3}{Q^{7/2}}\right\} + \frac{6L^2}{k_1^2}\left\{\frac{3}{Q^{5/2}} - \frac{30h^2}{Q^{7/2}}\right.$$

$$\left. + \frac{35h^4}{Q^{9/2}}\right\} + \frac{15}{k_1^3}\left\{ in^2\left[1-nL-L^2+2nL^3\right] - \frac{2(1-n)k_1de^{\theta}}{(1-n)-(1-n)e^{\theta}}\right\}$$

$$\times\left\{\frac{3h}{Q^{7/2}} - \frac{28h^3}{Q^{9/2}} + \frac{63h^5}{Q^{11/2}}\right\} + \ldots \qquad (3\text{-}9)$$

where $Q = (1+r^2)h^2$, $\quad r = \rho/h$.

The asymptotic expressions for $T(1,0)$, $T(0,0)$ and

$T(\mu,1)$ can be easily obtained by substituting appropriate values in (3-7) for a_ℓ and $N(\mu+\ell,\nu)$.

In (3-9) k_1 and L are complex, and they make the fourth and subsequent terms in the original expression (3-7) extremely cumbersome to work with. If we multiply (3-9) through by $Q^{3/2}$, we have

$$Q^{3/2}\ T(2,0) = g_0(r) + \frac{1}{(k_1 Q)} g_1(r,L) + \frac{1}{(k_1 Q)^2} g_2(r,L)$$

$$+ \frac{1}{(k_1 Q)^3} g_3(r,L) + \ . \ . \ . \tag{3-10}$$

The g-function can be obtained from (3-9). The right hand side of (3-10) would converge rapidly only when $k_1 Q >> 1$. Unfortunately k_1 is inversely proportional to $\sqrt{T}$, T being the period. In this study we are mainly concerned with long periods (up to 10^4 sec.), therefore the asymptotic expression has very limited use in what follows. However, when ρ and h are large (i.e. Q is large), the first three terms in (3-9) (i.e. terms with N(2,0), N(3,0) and N(4,0)) give excellent values for T(2,0) up to T = 20 sec. Some of these values for T(2,0) are given in the section 3.5 for checking purposes.

Similarly the integral $\tau(\mu,\nu)$ can be transformed into a power series in terms of the Taylor coefficients of $f(\lambda)$. Since $\tau(\mu,\nu)$ appears only once in the field components and the integral is to be evaluated by some other method,

its discussion is dispensed with here.

Instead of expanding $\chi(\lambda)$ and $f(\lambda)$ in Taylor series, fitting polynomials to them in the region of interest (which will be discussed in the next section) would also serve the purpose. However, this idea is not feasible when a large number of integrals of various parameters are to be evaluated, because $\chi(\lambda)$ depends on all these parameters. Each time a new parameter is introduced a new set of coefficients has to be evaluated for the polynomials. Therefore fitting polynomials to the complex functions has little advantage over Taylor series expansion, which requires laborious high order differentiation only once and for all.

3.2 Numerical Method for Evaluating Oscillating Integrals of the Type $\int_0^\infty \lambda^\mu \Omega(\lambda) J_\nu(\lambda a) e^{-\lambda b}\, d\lambda$

The integral $\int_0^\infty \lambda^\mu \Omega(\lambda) J_\nu(\lambda a) e^{-\lambda b}\, d\lambda$ (μ, ν being integers, a, b positive constants) appears very frequently in many of the wave propagation problems in geophysics. Under some circumstances it has been transformed to the complex plane and evaluated with the theory of residues. In some of these cases the complications involved in the integration about a branch point sometimes allows the authors only an asymptotic solution at large distances from the origin of disturbance.

Since numerical evaluation of these integrals forms a basic part of this thesis, a discussion of the general properties of these integrals are given below and a few numerical methods for their evaluation are compared. No doubt only the exploitation of a high speed computer makes it possible to evaluate the integral with even the simplest $\Omega(\lambda)$, therefore the following discussion will not be aimed at labour-saving but rather at an efficient way of acquiring results of desired accuracy for the integral. No analytical integration on the complex plane is attempted here, and $\Omega(\lambda)$ is assumed to be a mathematically simple and well-behaved function which has no singularity on the real axis along which the integration is carried out. Otherwise, $\Omega(\lambda)$ can assume any complicated form, either real or complex.

The exponential function in the integral permits the power μ to assume any finite value without impairing the properness of the integral. Since $\Omega(\lambda)$ is assumed to be well-behaved and the Bessel functions of first kind always have absolute values equal or less than unity, the absolute convergence of the integral can be easily established. However, the oscillating behaviour of the Bessel functions makes it very difficult to apply the conventional technique such as Laguerre-Gauss quadrature in the hope of obtaining a reasonable accuracy for the integral. It is particularly bad when ρ is large which makes the function oscillate very rapidly within a small range of λ.

An alternative method is to split the infinite in-

tegral into two integrals with limits from 0 to C and from C to infinity. One can then apply a rudimentary method such as Simpson's rule to evaluate the first integral, and the second one is discarded as error. However, the difficulty here is that the upper limit C of the first integral assums prime importance and a good estimate of it may not be an easy task. It is also necessary to re-estimate C each time an integral of different constant is evaluated. This makes the method undesirable when a large number of integrals containing various constants are to be evaluated.

The following is a method suggested by Longman (1956) to evaluate infinite oscillating integrals. Suppose a given integral $\int_0^\infty f(x)dx$ whose integrand f(x) oscillates about zero is to be evaluated, and suppose f(x) has zeros at $x_1, x_2, x_3 \ldots . x_q \ldots .$ Then we can write

$$\int_0^\infty f(x)dx = \int_0^{x_1} f(x)dx + \int_{x_1}^{x_2} f(x)dx + \ldots\ldots \int_{x_{q-1}}^{x_q} f(x)dx + \ldots$$

$$= S_1 + S_2 + \ldots\ldots + S_q + \ldots\ldots \tag{3-11}$$

The S alternate in sign. If the integral exists, the right hand side of (3-11) has to converge, and it is necessary that $|S_n| > |S_{n+1}|$ according to the theory of convergent alternating series. The sum of the series is given by

$$\int_0^\infty f(x)dx = \sum_{q=1}^{t} S_q + R \,, \quad \text{where} \quad |R| < |S_{q+1}| \tag{3-12}$$

If the series converges fast enough the summation of only a few terms will give good approximation for the integral. On the other hand, if it is a slowly convergent series, a large number of terms have to be taken and straight summation can still be a drudgery. It is the latter case that need special attention. Euler's transformation of slowly convergent alternating series can be used to alleviate this difficulty.

Euler's transformation is outlined as follows without proof (Bromwich, 1908, p. 55)

If we have a slowly converging alternating series

$$U = u_1 - u_2 + u_3 - \ldots .$$

where

$$u_n > 0, \; u_{n+1} < u_n \quad \text{for all } n,$$

and if we write $\Delta u_n = u_{n+1} - u_n$, $\Delta^2 u_n = \Delta u_{n+1} - \Delta u_n$, . . .

$$\Delta^{r+1} u_n = \Delta^r u_{n+1} - \Delta^r u_n$$

then $$U = \sum_{1}^{\infty} (-1)^n u_n = (\tfrac{1}{2})^1 u_1 - (\tfrac{1}{2})^2 \Delta u_1 + (\tfrac{1}{2})^3 \Delta^2 u_1 - \ldots \tag{3-13}$$

Thus U has been transformed from a slowly to a rapidly convergent series. This is a powerful approach because even for a very slowly convergent original series, an accuracy of 7 to 8 figures can be obtained within 20 terms.

The computation of each term is a simple matter of evaluating a definite integral. Either Simpson's rule or any other method of numerical integration can be used with great confidence. In this study the Gauss method of mechanical

quadrature using 16 ordinates (Lowan et al, 1942) is to be used.

Gauss method is based on the following principle. It states that if the integral $\int_{-1}^{1} f(y)dy$ is to be evaluated numerically with n ordinates, the best accuracy is obtained by choosing the corresponding abscissae at the n zeros of the nth degree Legendre polynomials $P_n(y)$. If we designate these zeros by $y_1, y_2, \ldots y_n$, then with each y_i is associated a constant a_i such that

$$\int_{-1}^{1} f(y)dy \sim a_1 f(y_1) + a_2 f(y_2) + \ldots + a_2 f(y_n) \qquad (3\text{-}14)$$

and

$$a_i = \frac{1}{P_n'(y_i)} \int_{-1}^{1} \frac{P_n(y)}{y - y_i} dy \qquad (3\text{-}15)$$

Any definite integral can be transformed into (3-14) by change of variable. For example,

$$\int_{p}^{q} f(y)dy = \frac{q-p}{2} \int_{-1}^{1} f(z \frac{q-p}{2} + \frac{q+p}{2})dz \qquad (3\text{-}16)$$

where y is replaced by $(z \frac{q-p}{2} + \frac{q+p}{2})$.

By (3-14)

$$\int_{p}^{q} f(y)dy = \frac{q-p}{2} \sum_{i=1}^{n} a_i f(z_i \frac{q-p}{2} + \frac{q+p}{2}) + R_n(f) \qquad (3\text{-}17)$$

where

$$R_n = \frac{f^{(2n)}(\xi)}{(2n)!k_n^2} \qquad (3\text{-}17a)$$

ξ is between p and q, and

$$k_n = \frac{({}_{2n}C_n)(2n+1)^{1/2}}{(q-p)^{n+1/2}} \tag{3-17b}$$

a_i and z_i with 15 significant figures have been calculated for n = 2 to 16 by Lowan et al (Lowan, Davids and Levenson, 1942).

3.3 A discussion of the integrand of $T(\mu, \nu)$

In order to evaluate $T(\mu, \nu)$, the complex function $\chi(\lambda)$ under the integral sign must be first decomposed into real and imaginary parts. This has been carried out in Appendix VII.

Figures 3a and b show the general behaviour of the real and imaginary parts of $\chi(\lambda)$. The abscissa of Figure 3b has been extended by a factor of 1.2 x 10^4 while that of 3a is unmodified. Thus 3b magnifies the very beginning portion of 3a. The imaginary parts of $\chi(\lambda)$ is an extremely well behaved function decreasing towards zero with increasing values of λ. The real part starts its slow oscillation at λ = .309 as shown in Figure 3a. It is extremely undesirable to have a product of two oscillating functions of different frequencies for the integrand. Fortunately our integration is confined to very small values of λ. This is clear from the following discussion by use of (3-22). In equation (3-22)

$$\lambda = \frac{y_{ij}}{rh} .$$

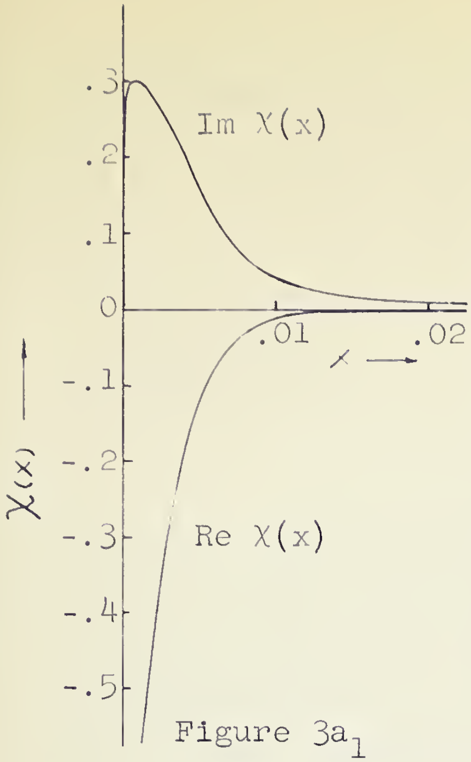


Figure $3a_1$

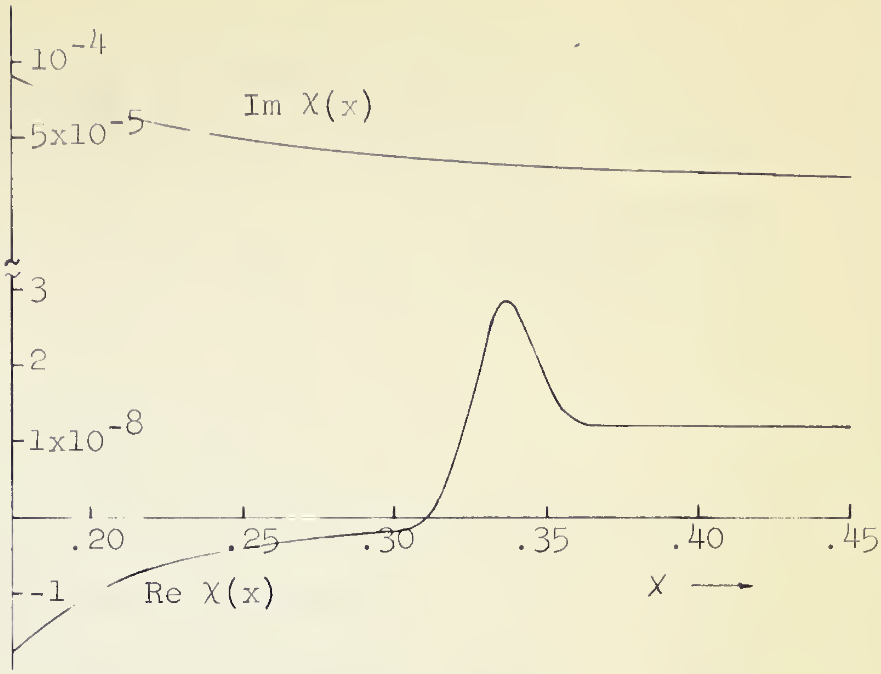


Figure $3a_2$

Real and Imaginary Parts of $\chi(x)$

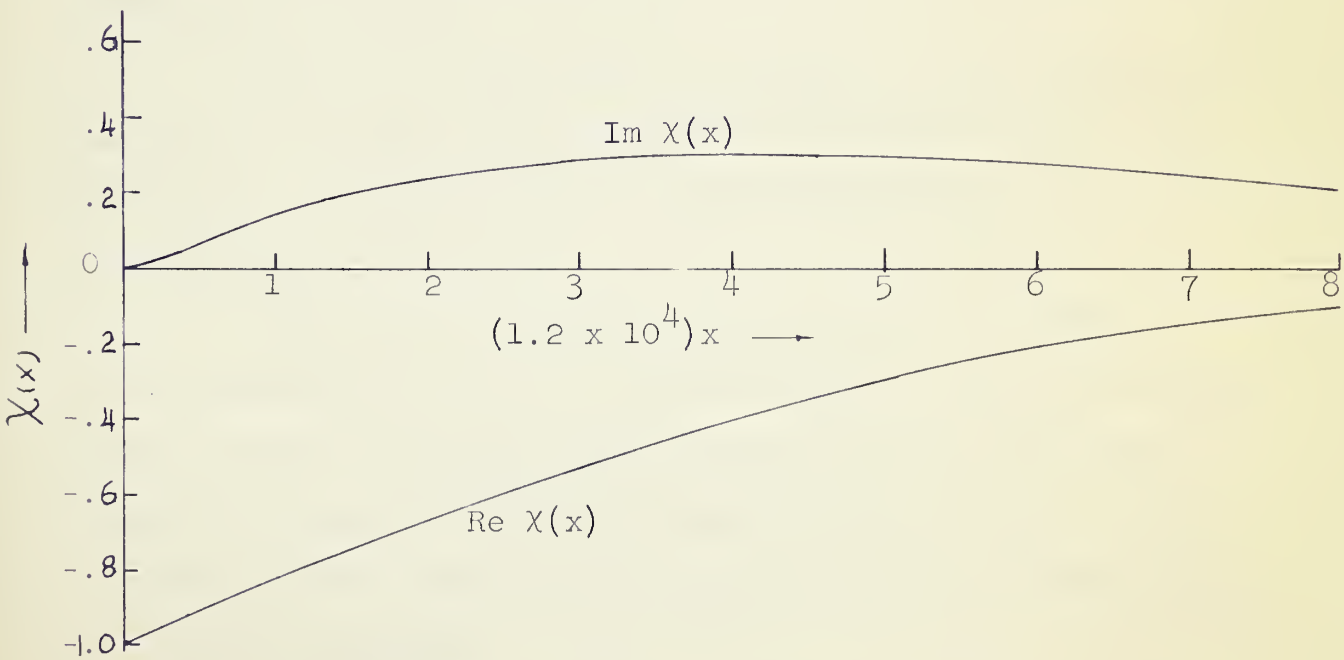


Figure 3b. Real and Imaginary Parts of $\chi(x)$

The maximum values of y_{ij} are the maximum zeros of J_0 and J_1 to be used which are 62.048 and 63.611 respectively (the 20th zero beyond the origin). Since $\chi(\lambda)$ is a monotone decreasing function of constant sign for $\lambda \lesssim .309$, the corresponding maximum value for rh is given by

$$rh \gtrsim \frac{63.6}{.309} \simeq 206 \ .$$

In this study h is taken to be 10^5, therefore for practical purposes, $\chi(\lambda)$ can be considered as a monotone decreasing function of constant sign within the range of interest. This constancy in sign imposes no modification upon the alternating nature of the integrated series (see 3-19 below). Consequently Euler's transformation can be applied freely if so desired.

At $r = 0$, or $\rho = rh = 0$, $J_0(0) = 1$, and $J_1(0) = 0$. All $T(\mu,1) = 0$, and the integrands of $T(\mu,0)$ oscillate slowly with $\chi(\lambda)$. Consequently the computation of $T(\mu,0)$ at $r = 0$ becomes less difficult.

For all discussions that follow $\chi(\lambda)$ is taken to be a decreasing function of constant sign. Upon this assumption, we shall presently make a careful study of the oscillating behaviour of the whole integrand and its rate of convergence. Both properties are decisive factors on the choice of integrating method.

For the convenience of discussion, let us rewrite $T(\mu,\nu)$ in the following form, with $\lambda h = x$, $r = \rho/h$

$$\int_0^\infty \lambda^\mu \chi(\lambda) J_\nu(\lambda\rho) e^{-\lambda h}\, d\lambda = \left(\frac{1}{h}\right)^{\mu+1} \int_0^\infty x^\mu \chi\left(\frac{x}{h}\right) J_\nu(rx) e^{-x}\, dx \qquad (3\text{-}18)$$

(3-18) shows that while the magnitude of the integral is regulated by h, the oscillating property depends upon r, the ratio of ρ to h.

Figure 4a shows a plot of $J_0(rx)e^{-x}$ against x. Suppose at x = b, e^{-b} is sufficiently small to make the portion of the integral beyond that point negligible. (This assumption is not unique because a different value of b is required for different r. In fact it increases with r. However this variation of b would help rather than hinder the discussion that follows.) Then the range of x between 0 and b is the range of integration. It is noted that the frequency of oscillation increases rapidly with r, and the larger the r, the less difference there is between the areas under the curve between the consecutive zeros. In other words, as r increases the integrated series loses its rate of convergence through two factors: higher frequency of oscillation and less difference between the areas between the zeros. The factors $\lambda^\mu \chi(\lambda)$ would only aggravate the situation since λ^μ would tend to reduce the effect of the exponential and $\chi(\lambda)$ is a fairly constant function except in the vicinity of the origin. Some examples in the next section will demonstrate this fact.

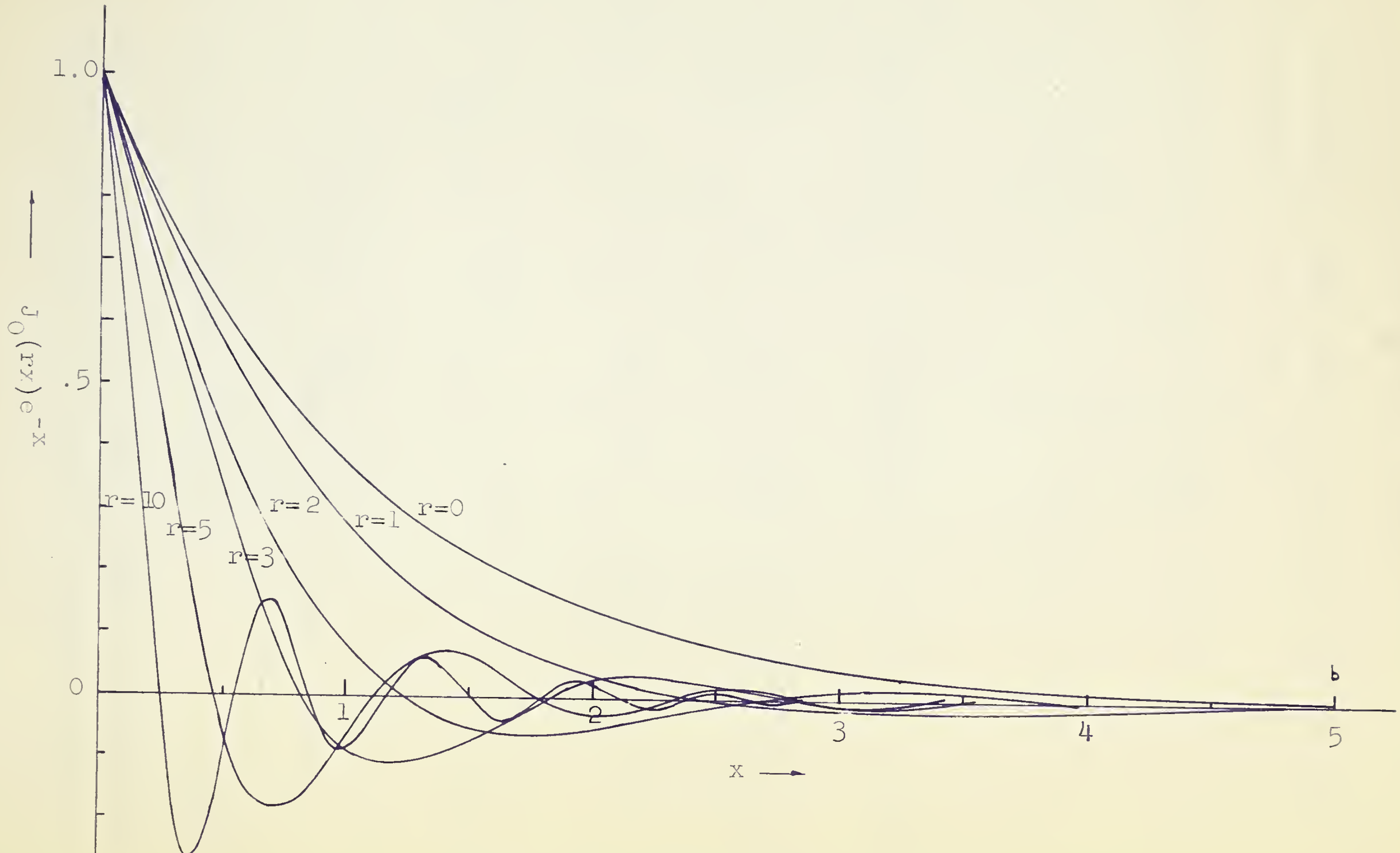


Figure 4a. Oscillation of $J_0(rx)e^{-x}$

3.4 Application of Gauss Method to $T(\mu,\nu)$

In order to apply Gauss quadrature to $T(\mu,\nu)$ we rewrite the integral as follows, with $x = \lambda\rho$, $r = \rho/h$,

$$\int_0^\infty \lambda^\mu \chi(\mu) J_\nu(\lambda\rho) e^{-\lambda h}\, d\lambda = \left(\frac{1}{rh}\right)^{\mu+1} \int_0^\infty x^\mu \chi\left(\frac{x}{rh}\right) J_\nu(x) e^{-x/r}\, dx$$

$$= \left(\frac{1}{rh}\right)^{\mu+1} \left\{ \int_0^{x_1} + \int_{x_1}^{x_2} + \ldots \int_{x_i}^{x_{i+1}} x^\mu \chi\left(\frac{x}{rh}\right) J_\nu(x) e^{-x/r}\, dx + \ldots \right\}$$

$$= \left(\frac{1}{rh}\right)^{\mu+1} \lim_{M\to\infty} \sum_{i=0}^{M} \int_{x_i}^{x_{i+1}} x^\mu \chi\left(\frac{x}{rh}\right) J_\nu(x) e^{-x/r}\, dx \tag{3-19}$$

where x_i is the i^{th} zero of $J_\nu(x)$ beyond the origin, and $x_0 = 0$.

Apply (3-16) and (3-17) to the integral in (3-19)

$$\int_{x_i}^{x_{i+1}} x^\mu \chi\left(\frac{x}{rh}\right) J_\nu(x) e^{-x/r}\, dx = \frac{x_{i+1} - x_i}{2} \int_{-1}^{1} y_i^\mu \chi\left(\frac{y_i}{rh}\right) J_\nu(y_i) e^{-y_i/r}\, dz$$

$$\simeq \frac{x_{i+1} - x_i}{2} \sum_{j=1}^{n} a_j y_{ij}^\mu\ \chi\left(\frac{y_{ij}}{rh}\right) J_\nu(y_{ij}) e^{-y_{ij}/r} \tag{3-20}$$

where a_j is a constant given in (3-15)

$$y_i = \left\{ z\,\frac{x_{i+1} - x_i}{2} + \frac{x_{i+1} + x_i}{2} \right\} \qquad \text{and}$$

$$y_{ij} = \left\{ z_j\,\frac{x_{i+1} - x_i}{2} + \frac{x_{i+1} + x_i}{2} \right\} \tag{3-21}$$

where z_j denotes the j^{th} zero of the n^{th} degree Legendre polynomial. For $n = 16$, a_j and z_j are given in Appendix VIII.

Combining (3-20) and (3-19), we have

$$T(\mu,\nu) \simeq \left(\frac{1}{rh}\right)^{\mu+1} \lim_{M\to\infty} \sum_{i=0}^{M} \left\{ \frac{x_{i+1} - x_i}{2} \sum_{j=1}^{n} a_j y_{ij}^{\mu} \, \chi\left(\frac{y_{ij}}{rh}\right) J_\nu(y_{ij}) e^{-y_{ij}/r} \right\} \tag{3-22}$$

The approximation sign is used in (3-20) and (3-22) because (3-20) does not include the error given by (3-17a). The error in (3-22) can be easily obtained in the computation and will be shown below.

χ in (3-22) is a complex function. If we replace χ by (Re χ + i Im χ), (3-22) will give the imaginary and real parts of the integral $T(\mu,\nu)$. Figure 4b illustrates the relation in (3-22) graphically.

The right hand side of (3-22) is a difficult function to compute because of the Bessel function of an argument dependent upon M, M being the number of zeros to be used in the computation. The 20th zero of $J_0(x)$ is at $x = 62.048 \ldots$, and the corresponding zero of $J_1(x)$ is at $x = 63.6113 \ldots$. The computation of $J_0(x)$ and $J_1(x)$ of such large arguments is a time consuming and painstaking job even with a high speed computer. This is the chief reason for transforming $T(\mu,\nu)$ into the form of (3-19) and then (3-22) with the argument of the Bessel function as the variable of integration which is independent of r. Otherwise, a new set of J_ν value would be required for different r in (3-22).

Fortunately there are tables of Bessel functions of large arguments and high accuracy available. One such

[illegible]

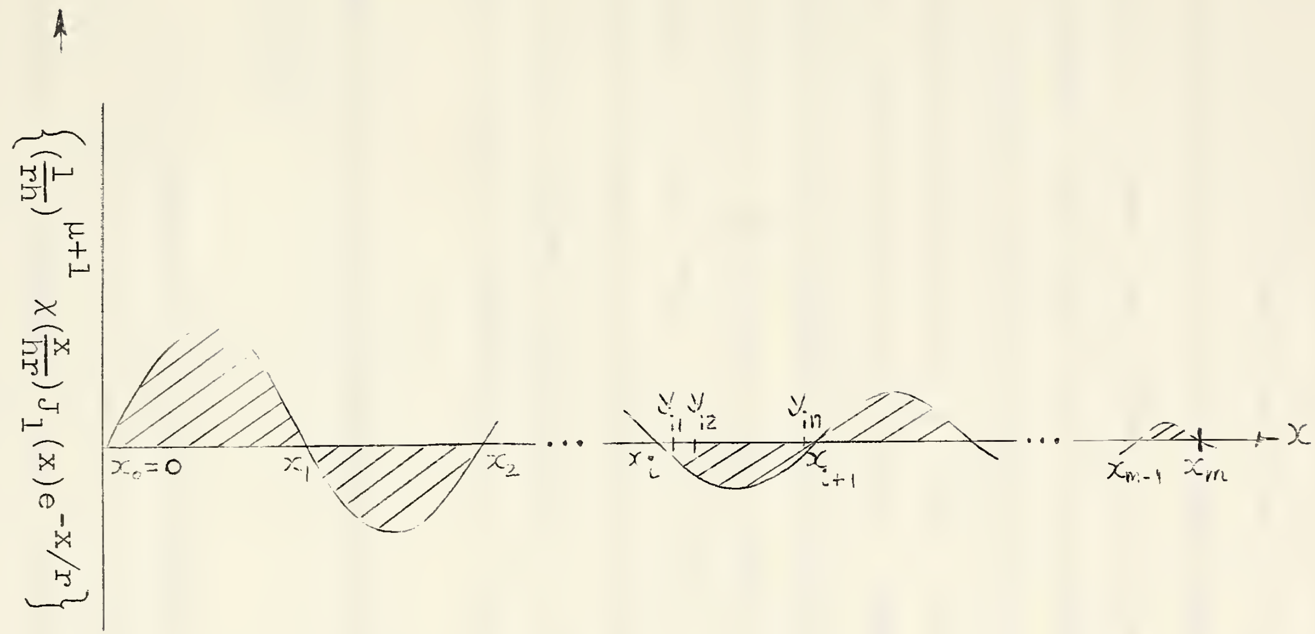


Figure 4b. Relation of (3-22). Series cut off at x_m .

y_{ij} are abscissae.

table was published by the Harvard University Computation Lab. (1947). It contains $J_0(x)$ and $J_1(x)$ to 18 significant figures with small increments of x up to x = 100. The zeros of $J_0(x)$ and $J_1(x)$ can be obtained from "zeros of $J_0(x)$ and $J_1(x)$" by the British Association for the Advancement of Science (1950). With the aid of these two tables all values of y_{ij} in (3-22) can be computed from (3-21) and the corresponding $J_\nu(y_{ij})$ can be computed by either extrapolation or Taylor's expansion from the tables up to $y_{ij} = 100$. These values are computed once and for all computations. Longman (1957) has computed y_{ij} for 16 ordinates and in between each of the first 20 zeros of $J_0(x)$ and $J_1(x)$, and they are used in the computation in this thesis. The accuracy of these values has been spot checked, and has been confirmed by Professor Longman through private communication. Some other means have been devised for checking in the next section.

3.5 Computation of the Integrals and a Discussion of Their Accuracy

The computation of the integrals has been carried out with the IBM 1620 computer in the Computing Centre of the University of Alberta by use of (3-22) with a maximum M = 20, and n = 16. Four values of r, 0, .2, 3, 5 have been used in the computation and the results are given in Appendix IX. Since we confined our attention to the near fields of the dipole (say, $r \leq 5$). Euler's transformation has not

[illegible]

been used in the computation. The following tables show that 20 terms in the integrated series are adequate to ensure at least 4 significant figures for the integrals $r < 3$. The following values were all computed with the common constants, $\sigma_1 = .2\ (\text{ohm-m})^{-1}$, $\sigma_2 = .002\ (\text{ohm-m})^{-1}$, $d = 4{,}000$ m, $h = 10^5$ m, T = period in sec. The first column indicates the terms in a series, e.g. in Table 1, 3 terms have been calculated, in Table 2, 10 terms and so on. The row headed sum is the sum of all previous terms. It is therefore the real and imaginary parts of the integrals. The maximum error in each case is bracketed. The number of terms required increases with r (3 for r = .2, 10 for r = 1, 19 for r = 2, etc.).

Table 1

[illegible] T(0,0), r = .2, T = 10 sec.

	Real part	Imaginary part
1	-.95426515E-05	.32356982E-06
2	.31024207E-11	-.17862421E-11
3	(-.11933114E-18)	(.18138217E-18)
Sum	-.95426484E-05	.32356804E-06

Table 2

T(2,0), r = 1, T = .10 sec.

	Real part	Imaginary part
1	-.39998709E-15	.17378081E-17
2	.24821618E-15	-.32606974E-17
3	-.27964062E-16	.67030165E-18
8	.24830720E-22	-.19793281E-23
9	(-.12922339E-23)	.11751366E-24
10		(-.67139900E-26)
Sum	-.17773021E-15	-.92178287E-18

Tabe 3

T(2,0), r = 2, T = .10 sec.

	Real part	Imaginary part
1	-.95033477E-16	.22634173E-18
2	.20882241E-15	-.14526412E-17
3	-.10835602E-15	.13407006E-17
15	-.10979537E-22	.87170880E-24
16	.25130497E-23	-.21363307E-24
17	(-.57144307E-24)	.51789457E-25
18		-.12434991E-25
19		(.29604340E-26)
Sum	.35395206E-16	-.38082729E-18

Table 4

T(2,0), r = 3, T = .10 sec.

	Real part	Imaginary part
1	-.35339125E-16	.57735433E-19
2	.11973953E-15	-.56591178E-18
3	-.10340158E-15	.86229681E-18
17	-.84168178E-21	.50872305E-22
18	.32186338E-21	-.20656300E-22
19	-.12245641E-21	.83165848E-23
20	(.46378245E-22)	(-.33231686E-23)
Sum	.22051560E-16	-.84434675E-19

Table 5

T(2,1), r = 5.0, T = .10 sec.

	Real part	Imaginary part
1	-.28943090E-16	.49440123E-19
2	.54757998E-16	-.21287378E-18
3	-.57478893E-16	.35109272E-18
4	.48766157E-16	-.40656255E-18
17	-.12710157E-18	.47535367E-20
18	.73802197E-19	-.29253359E-20
19	-.42649324E-19	.17859760E-20
20	(.24541135E-19)	(-.10826190E-20)
Sum	-.43552524E-17	-.12885695E-19

Table 6

T(2,1), r = 5.0, T = 100 sec.

	Real part	Imaginary part
1	-.27796499E-16	.37398440E-17
17	-.66179143E-20	.25305872E-19
18	.33476806E-20	-.13704363E-19
19	-.16944402E-20	.74021566E-20
20	(.85821373E-21)	(-.39892959E-20)
Sum	-.46027211E-17	-.96950058E-18

Table 7

T(2,1), r = 5.0, T = 10,000 sec.

	Real part	Imaginary part
1	-.40100106E-18	.27279198E-17
2	.57594689E-19	-.17218553E-17
3	-.21029259E-19	.10698919E-17
17	-.70314847E-24	.27062556E-21
18	.35267515E-24	-.14535635E-21
19	-.17728650E-24	.77970486E-22
20	(.89244312E-25)	(-.41775644E-22)
Sum	-.35830661E-18	.16739434E-17

Table 8

T(0,1), r = 5.0, T = .10 sec.

	Real part	Imaginary part
1	-.19508362E-05	.24184723E-08
2	.48208093E-06	-.18128680E-08
3	-.19887446E-06	.11991679E-08
17	-.11519300E-10	.43067117E-12
18	.59549377E-11	-.23596821E-12
19	-.30833690E-11	.12908394E-12
20	(.15988102E-11)	(-.70513586E-13)
Sum	-.16064254E-05	.13413909E-08

For r = 3.0, 20 terms give only six significant figures for the real part and four for the imaginary part. Table 5 gives T(2,1) for r = 5.0 and T = .10 sec. It is obvious that the accuracy for both the real and imaginary parts are quite poor (two and one figures respectively). However, as T increases the accuracy for both the real and the imaginary parts improves. Table 6 shows that at T = 100 sec., the real part is accurate to four places and the imaginary part to three places, while for T = 10,000 sec., Table 7 shows that the accuracy of the integral has greatly increased to seven and five figures for the real and imaginary parts respectively.

If Table 8 (T(0,1)) is compared with Table 5 (T(2,1)), r and T being equal in both cases, one again finds an improve-

ment in the accuracy. This comparison shows that all other constants being equal, the accuracy of the integrals decreases with μ. This is not at all surprising because as shown in equation (3-22), the rate of convergence of the integrated series which depends upon the factor $(y_{ij}^{\mu}\ e^{-y_{ij}/r})$ decreases as μ and r increases.

One can generalize the accuracy of the computed integrals $T(\mu,\nu)$ as follows: the accuracy of both the real and imaginary parts (1) decreases as r increases, (2) decreases as μ increases, and (3) increases with the period T. In all cases, the accuracy of the real part is at least one figure better than the imaginary part. The values of $T(2,\nu)$ for r = 5.0 are not sufficiently accurate for computations of the field components at the low period end. The worst of all computed values are T(2,0) and T(2,1) for r = 5, T = .10 sec. The latter and the 20 integrated terms from which it is computed are shown in Table 5.

The sources of error are threefold, namely (1) the reliability of the overall method, (2) accuracy of the abscissae and the corresponding values of the Bessel function, and (3) the logic of programming.

We notice that $T(\mu,\nu)$ differs from $N(\mu,\nu)$ by the complex factor $\chi(\lambda)$. If we set $\chi(\lambda) = 1$ the $T(\mu,\nu)$ and $N(\mu,\nu)$ are identical. Since $N(\mu,\nu)$ can be evaluated analytically (Appendix V) its value can be easily obtained with high precision by a hand calculator. Therefore, if $T(\mu,\nu)$ is computed with $\chi(\lambda) = 1$, and if the result is equal to that of

$N(\mu, \nu)$ with the same parameters, we are sure that the method is reliable and that the abscissae and the corresponding Bessel functions are free of error. The following are two integrals N(1,1) and N(2,0) thus obtained from the computer by use of the program with data for T(1,1) and T(2,0), i.e. r = 2.0, σ_1 = .2 mho/m, σ_2 = .002 mho/m, h = 10^5 m.

$$N(1,1) = T(1,1)\Big|_{\chi(\lambda)=1} = .17888539\text{E-}10\ , \qquad 14 \text{ terms used.}$$

$$N(2,0) = T(2,0)\Big|_{\chi(\lambda)=1} = -\ .35777097\text{E-}16\ , \qquad 18 \text{ terms used.}$$

The values can be compared with the following which have been calculated by hand from equations given in Appendix V:

$$N(1,1) = \frac{r}{h^2(1 + r^2)^{3/2}} = .178885440 \times 10^{-10}$$

$$N(2,0) = \frac{(2 - r^2)}{h^3(1 + r^2)^{5/2}} = -\ .357770876 \times 10^{-16}$$

The above values confirm the method used and the accuracy of the Bessel functions. However, this has not freed the program of logic error in $\chi(\lambda)$, because it has not been used in the above computation.

Fortunately, the physical situation of the problem provides a convenient check for $\chi(\lambda)$. Physically $\chi(\lambda)$ takes care of the boundary conditions and layering effects. Therefore, if an identical physical situation can be created through the manipulation of the parameters in $\chi(\lambda)$, using these different parameters we would expect the values of the integral to be identical. This is illustrated as follows:

A homogeneous earth of conductivity σ corresponds to models (a) $\sigma_1 = \sigma_2 = \sigma$, (b) $d = 0$, $\sigma_2 = \sigma$, and (c) $d \longrightarrow \infty$, $\sigma_1 = \sigma$; therefore these should all give identical values for the integrals. This has been confirmed and thus $\chi(\lambda)$ has been convincingly, though not conclusively, proven to be correct, since assuming a homogeneous earth automatically excludes all layer effects that $\chi(\lambda)$ stands for.

A last check of the integrals can be done with the asymptotic expansion as given in (3-9). If $k_1 Q$ is sufficiently large, we can approximate $T(\mu, \nu)$ by

$$T(\mu,\nu) = \sum_{\ell=0}^{2} a_\ell N(\mu+\ell,\nu) \qquad (3\text{-}23)$$

as the first 3 terms in (3-9). For $h = 10^5$, $\sigma_1 = .2$

$$k_1 \simeq \sqrt{i\omega\mu_0\sigma_1} = \sqrt{i}\ \frac{1.25 \times 10^{-3}}{\sqrt{T}}$$

$$k_1 Q = \sqrt{i}\ \frac{1.25 \times (1+r^2)^{1/2} \times 10^2}{\sqrt{T}}$$

at $r = 3$

$$k_1 Q \simeq \sqrt{i}\ \frac{395}{T}$$

In order to have reasonable results by 3 term expansion, $k_1 Q$ must be much larger than 1. The following two tables give the values of $T(2,0)$. Table 9 is computed from the integral and Table 10 from the series. It is noted that as T increases, the accuracy decreases in Table 10 because $k_1 Q \gg 1$ does not hold at high periods.

Table 9

Computation from Integral

T(2,0)

r = .30E+01, S1 = .2000E-00, S2 = .2000E-02, D = .40E+04,
E = .10E+06

T (sec)	Real Part	Imaginary Part
.10	.22051560E-16	-.84434675E-19
.20	.22016603E-16	-.11943250E-18
.50	.21947217E-16	-.18889501E-18
1.00	.21869070E-16	-.26778590E-18
2.00	.21753361E-16	-.37560499E-18
5.00	.21576676E-16	-.55750119E-18
10.00	.21487620E-16	-.85363732E-18
20.00	.21408214E-16	-.15012673E-17
50.00	.21353261E-16	-.34613961E-17
100.00	.21426352E-16	-.76219350E-17
200.00	.15889079E-16	-.17092902E-16
500.00	-.52220677E-17	-.15555217E-16
1000.00	-.96081510E-17	-.38133709E-17
2000.00	-.60542829E-17	.20451163E-17
5000.00	-.19715858E-17	.25454967E-17
10000.00	-.71423302E-18	.16613346E-17

Table 10

Computation from Series

T(2,0)

r = .30E+01, S1 = .2000E-00, S2 = .2000E-02, D = .40E+04, E = .10E+06

T (sec)	Real part	Imaginary Part
.10	.22051552E-16	-.84434511E-19
.20	.22016597E-16	-.11943304E-18
.50	.21947243E-16	-.18889898E-18
1.00	.21869095E-16	-.26779805E-18
2.00	.21753418E-16	-.37563445E-18
5.00	.21577021E-16	-.55787437E-18
10.00	.21487943E-16	-.85580907E-18
20.00	.21404267E-16	-.15135765E-17
50.00	.21175092E-16	-.34955363E-17
100.00	.20740263E-16	-.66427873E-17
200.00	.19780280E-16	-.12516092E-16
500.00	.16859265E-16	-.28355337E-16
1000.00	.12596650E-16	-.52052511E-16
2000.00	.62131989E-17	-.95667344E-16
5000.00	-.41475307E-17	-.21906589E-15
10000.00	-.10761902E-16	-.42140897E-15

The imaginary parts are less accurate than the real parts. This is expected since in (3-23), the first term is real. Only the second and third terms are complex. In other words, the real part is calculated from one more term than the imaginary part.

The integral $\tau(\mu,\nu)$ is more complicated because $f(\lambda)$ has a singularity at $\lambda = 0$. In fact $\tau(0,0)$ is divergent. However the following integrals exist:

$$\tau(\mu,1) \;, \qquad \mu = 0,\ 1,\ 2\ .\ .\ .$$

$$\tau(\mu,0) \;, \qquad \mu \geqslant 1$$

In this study, we only use $\tau(2,1)$ to compute the radial E component of the vertical electric dipole. Some of the values of $\tau(2,1)$ are given in Appendix IX. The analysis for $\tau(2,1)$ is exactly the same as for $T(\mu,\nu)$, with $\chi(\lambda)$ replaced by $f(\lambda)$.

IV. PROPERTIES OF E AND H FIELD COMPONENTS ON THE SURFACE OF A 2-LAYERED EARTH

The electric and magnetic field components as summarized in Chapter II are computed by use of the integrals evaluated in Chapter III. The fields are computed for a constant source elevation h at four radial distances: $\rho = 0$, .2 h, 3 h and 5 h. For the horizontal dipole, whose fields are angularly dependent, four angular distances from the x-axis, $\varphi = 0$, $\pi/6$, $\pi/3$ and $\pi/2$ radians are used. At each space point, the fields are computed at 16 discrete periods T = .1, .2, .5, 1, 2, ..., 5,000, 10,000 sec. This is in conformity with many geophysical observations which are usually carried out at a particular spot but are composed of a band of frequencies instead of a single one.

4.1 Characteristics of the Fields on the Surface of the Earth

(A) Vertical magnetic dipole fields:-

The fields of a vertical magnetic dipole as given in Appendix X are plotted in Figure 5. It is noted that the H_z components are increasing with period for all r while the H_ρ components level off and then decrease at $T = 10^3$ sec. The total H (approximated by H_ρ up to $T \sim 100$ sec.) exhibits

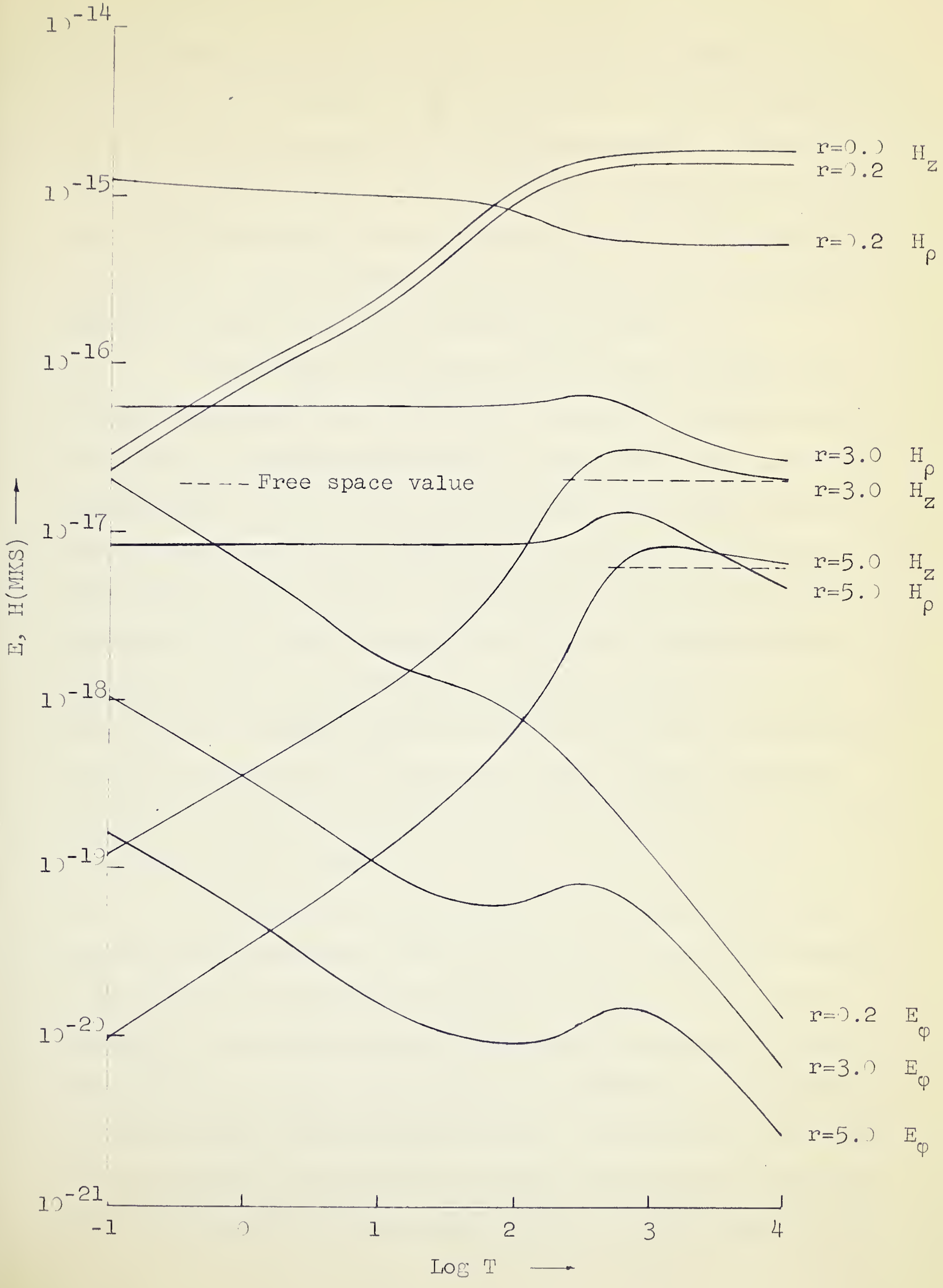


Figure 5. V.M.D. Fields at z = 0

little frequency dependence up to T = 100 sec. and then starts to increase with period. For r = 0 and .2, total H again attains a constant value ($\sim 2 \times 10^{-15}$ amp-turn/m). However, for r = 3.0 and 5.0 the total H starts increasing at T $\sim$ 500 sec., leaving behind a hump which becomes more pronounced as r increases. E_φ decreases rapidly as the period increases. Humps also appear in E corresponding to those in H.

These humps are present in all $T(\mu,\nu)$ within the period range from 200 - 1000 sec. Therefore, mathematically the complex integrals are entirely responsible for these irregularities. It is true that the field components are combinations of both $N(\mu,\nu)$ and $T(\mu,\nu)$. However, $N(\mu,\nu)$ are independent of the period, therefore the shape of the field components are characterized by the complex integral $T(\mu,\nu)$. Physically, the entire family of $T(\mu,\nu)$ represent at least part of the secondary fields which are the direct consequence of the presence of the conducting earth. We can therefore classify these irregularities of the E - H fields as strictly a secondary phenomenon.

It is interesting to note that the period of the hump maximum progresses with r; so does its relative strength. A very possible explanation for these humps is wave interference at the surface due to the conducting layer of finite thickness in analogy to the thin film interference phenomenon in optics due to multiple reflection. It is however not easy to describe the interference patterns quantitatively because the incident waves are not plane waves. Another approach to

show that these irregularities are in fact due to multiple reflection from the lower interface would be to remove the interface by considering a homogeneous earth, or to vary the thickness of the layer at constant rate. In the former case the humps should disappear with the removal of the layer. In the latter case the displacement of the humps should be in some regular fashion as 'd' varies regularly.

Figures 6, 7 and 8 show the variation of the absolute amplitudes of the components of the electric and magnetic vectors as a function of radial distances from the origin. Since these plots are based upon four points only, i.e. $r = 0$, .2, 3 and 5, they should only be considered as a guide to the space variation of the fields. The primary field (or free space field) in each component is plotted as dashed lines.

Figure 6 shows the space variation of the field strength of both the free space value and the total value (primary + secondary) of E_φ of a vertical magnetic dipole. One notices two obvious variations:

(a) At a given r, the total field strength of E_φ approaches the free space value as T increases. For example, at $r = 1$, $T = .1$ sec., the free space field is larger than the total field by a factor of 100 while at $r = 1$, $T = 10^4$ sec., the free space field and the total field are nearly equal. This variation is expected. In fact as $T \to \infty$, the source becomes a D-C source and all the induced effect vanishes. Therefore the fields of such a source in presence of the earth should approach that of the same source when the

earth is not present, which is the free space field.

(b) For a given period, the difference between the free space and the total fields increases with r. For example, at T = .1 sec., free space E_φ/total E_φ ratio $\sim$ 100 at r = 0.5 but the same ratio $\sim$ 2000 at r = 5.0. Since the difference is due to the presence of the earth, the effect of the earth assumes great importance in comparison with the primary field as r increases. This can probably be explained with the concept of surface waves introduced by Sommerfeld when he analyzed the dipole fields on the surface of a homogeneous earth. The term that represents surface wave is in fact a residue of the complex integral and the potential of this wave varies with $1/\sqrt{r}$. As we have seen earlier the primary Hertz potential varies as 1/r, therefore as r increases the surface waves become more and more appreciable. Note that the field interpolated between r = .2 and 3 is guided by the primary field.

Figure 7 shows H_ρ at T = .1 sec. and 10^4 sec. The dashed line is the free space field. Both the variations (a) and (b) cited in the last paragraph are also present. (Note that variation (b) is small and cannot be shown in the graph.) It is worth noting that E_φ and H_ρ approach the free space value from two opposite directions as T increases. This is due to the fact that the induced E_φ tends to cancel out the primary E_φ while the H_ρ's reinforce each other. If the earth were a perfect conductor, H_ρ would be twice as large as the free space field. Figure 7 also supports this

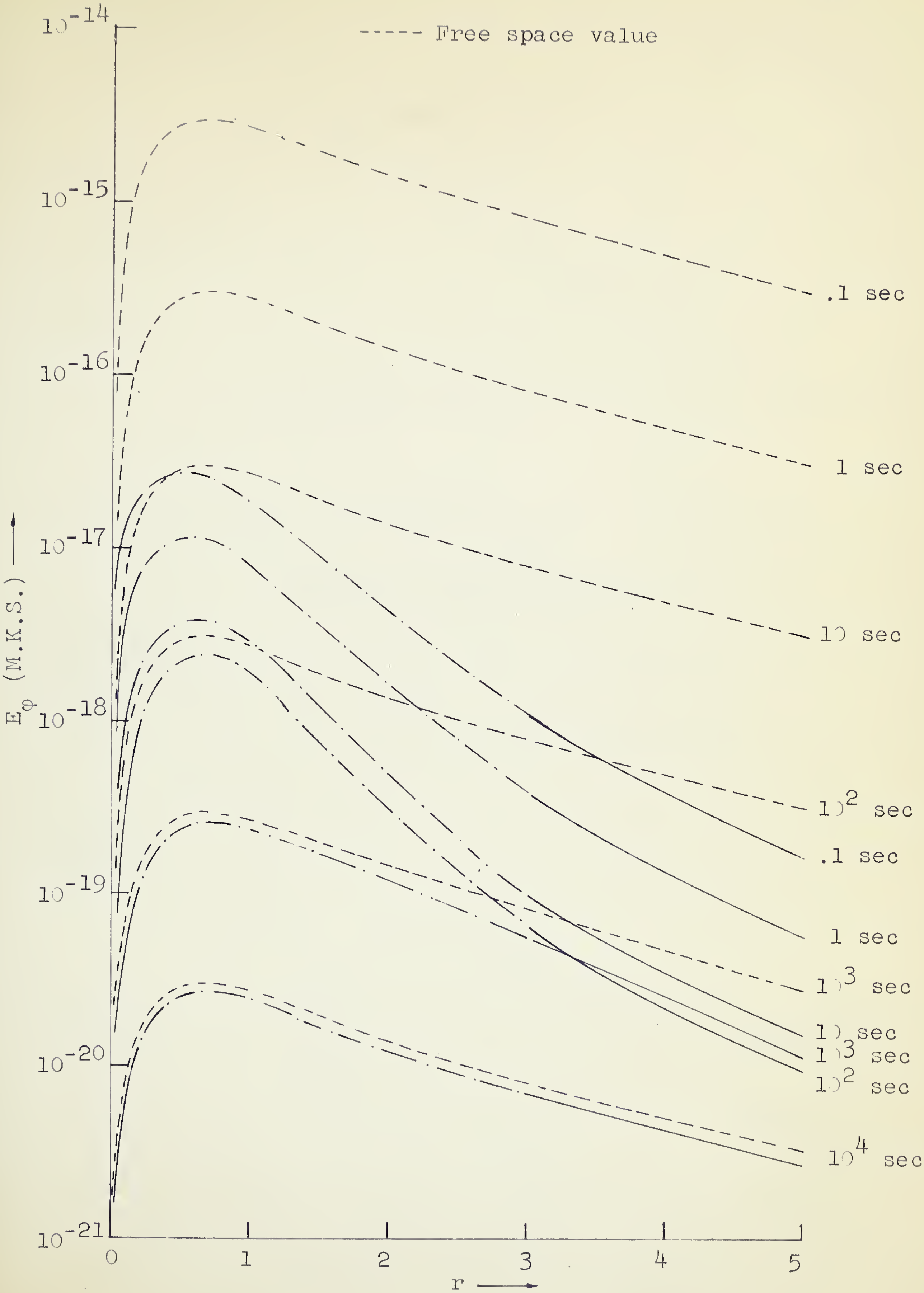


Figure 6. Space variation of E_φ of a V.M.D. at z = 0

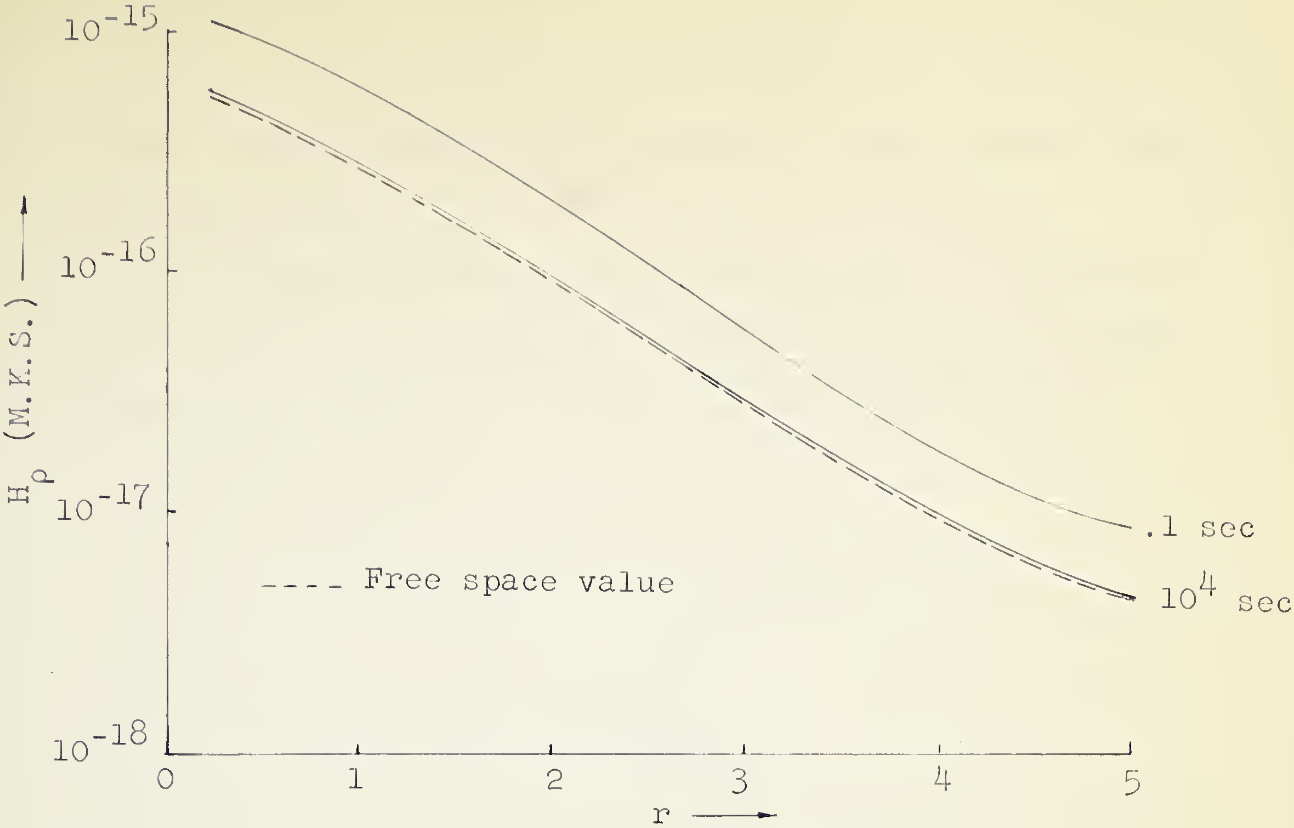


Figure 7. H_ρ of a V.M.D.

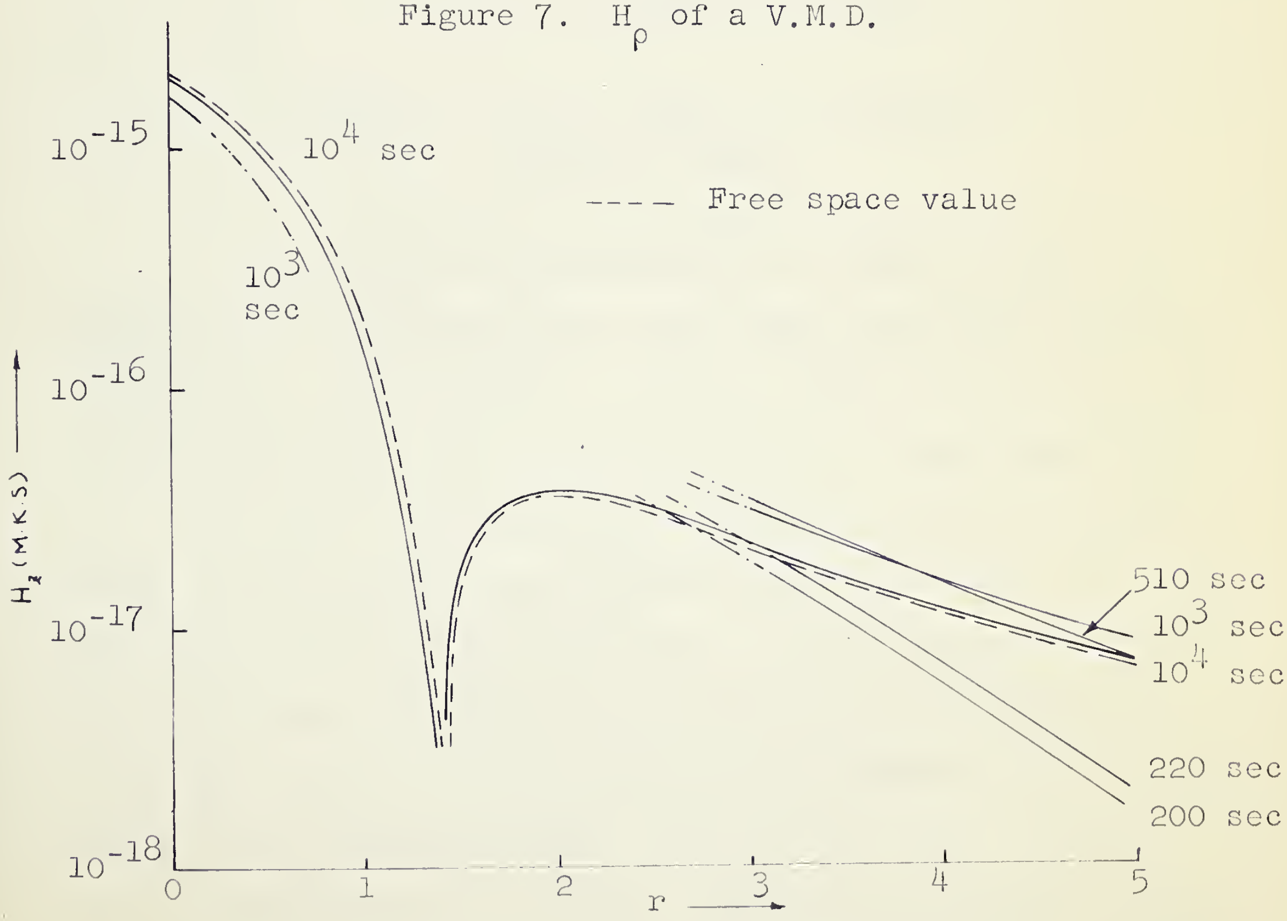


Figure 8. H_z of a V.M.D.

argument, since the ratio of H_ρ at T = .1 sec. to free space H_ρ is almost two.

Figure 8 shows H_z as a function of r. A discontinuity of log H_z occurs at $r \sim \sqrt{2}$ where $H_z = 0$ at $z = 0$ and changes sign. Physically this is clear from Figure 9.

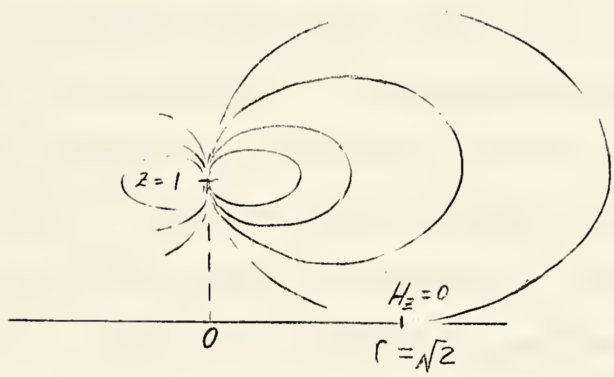


Figure 9. Field lines of a vertical magnetic dipole

It is worth noting that for $r < \sqrt{2}$, the vertical magnetic field approaches the free space value from below as T increases. However, for $r > \sqrt{2}$, H_z varies in a rather complicated fashion. At r = 3, H_z attains the free space value at T ~ 220 sec. (cf. Fig. 5) and a maximum value of approximately twice the free space value at 550 sec. At r = 5, the free space value is attained at T ~ 510 sec. and the maximum at T ~ 1500 sec. In general, for $r > \sqrt{2}$, H_z surpasses the free space value at various frequencies dependent upon r and then attains a maximum value. It decreases again towards the free space value as a limit. As mentioned earlier, this confused state is possibly due to wave interference. However,

it is not clear why this phenomenon manifests itself only beyond $r = \sqrt{2}$ for the earth model we use in this study.

(B) Horizontal magnetic dipole fields:

The surface components of the horizontal magnetic dipole fields are a great deal more complicated than those of the vertical magnetic dipole in two aspects: (i) the former are angularly dependent while the latter are not, (ii) the components of the electric vector and the magnetic vector of the vertical dipole are orthogonal on the surface of the earth while those of the horizontal dipole are not. These depend on r, φ and T as shown in Figure 15. For a horizontal dipole, at r = 0, the field cannot be computed directly from the equations summarized at the end of Chapter II. They are given in Appendix II.

All computed field components at $\varphi = 0, \pi/6, \pi/3, \pi/2$ and r = 0, .2, 3, 5 are given in Appendix X. All discontinuities at long periods are due to sign reversal of the field components. At r = 3 and 5, the signs of the E_y reverse at a somewhat longer period than do those of H_z. They will be further discussed later. A disturbing fact in Figure 10 is a double sign reversal in E_x at r = .2. Since E_y is approximately 40 times as large as E_x the reversed sign (from + ve to - ve) would cause very slight angular displacement of the horizontal $|H|$ in space. Nevertheless it is a baffling phenomenon that is not understood.

Figure 10 shows the H_z components approaching the

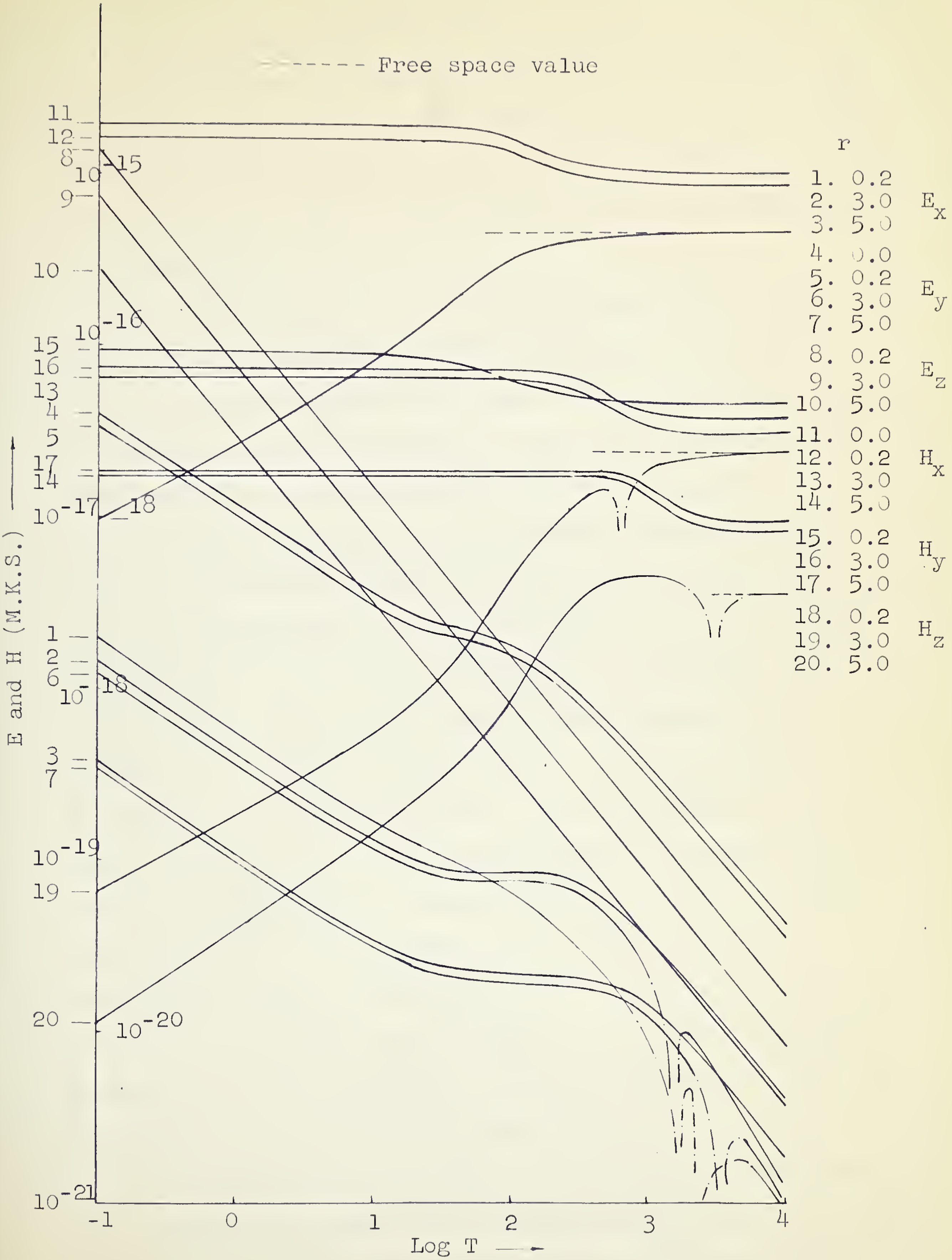


Figure 10. E and H Fields of a H.M.D. at z = 0, $\varphi = 30^{\circ}$

free space values in different manners at different r. One obvious result is that the smaller the r the smaller is the period at which the earth starts losing its influence on the field strength. This is also true with all the other magnetic components.

Figures 11 to 14 are plots of the total horizontal field strengths against r on the surface of the earth.

Figure 11 shows the space variation of the horizontal $|H|$ on the earth's surface. Since the values are computed only at r = 0, .2, 3 and 5, variations between r = .2 and 3 as shown in Figure 12 are smoothly interpolated and may not be accurate. Figure 12 shows the free space horizontal $|H|$ corresponding to those in Figure 11 at $T = 10^4$ sec. Between r = 0 and 1.4, the horizontal $|H|$ decreases with the angle φ (this is also true with the earth present as can be checked at r = 0.2). In fact at $\varphi = 0$ the horizontal H vanishes at $r \simeq 0.7$ in free space. As φ increases, the horizontal $|H|$ increases. The minimum gradually disappears as φ increases towards 60°. Appendix III shows that this minimum should entirely disappear at $\varphi = 54^\circ 20'$. Physically, these minima appear wherever $H_x = 0$. It is shown in Appendix III that these space points, where $H_x = 0$, form a hyperbola symmetrical about the origin with the x-axis as its axis and the lines $\varphi = \pm 54^\circ 20'$ as its asymptotes.

Figure 13 shows Figure 11 superimposed upon Figure 12. It should be noted that at long periods the total fields are almost identical with the free space field as expected

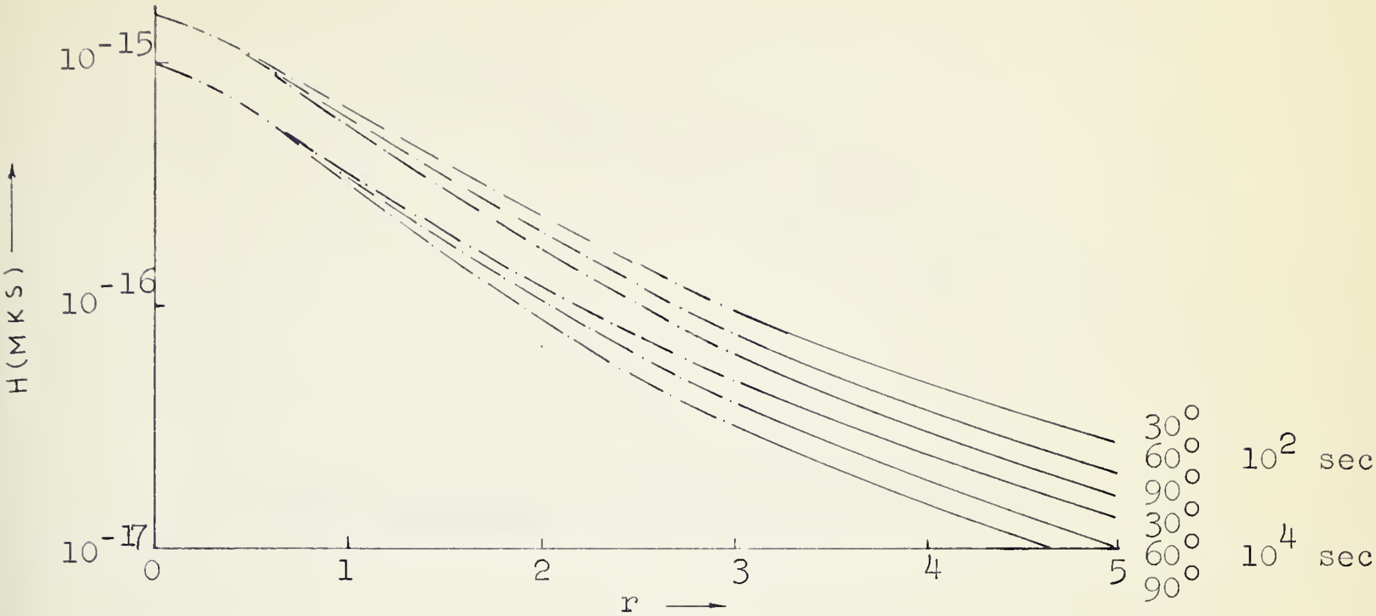


Figure 11. Space variation of | H | of a H.M.D. at z = 0

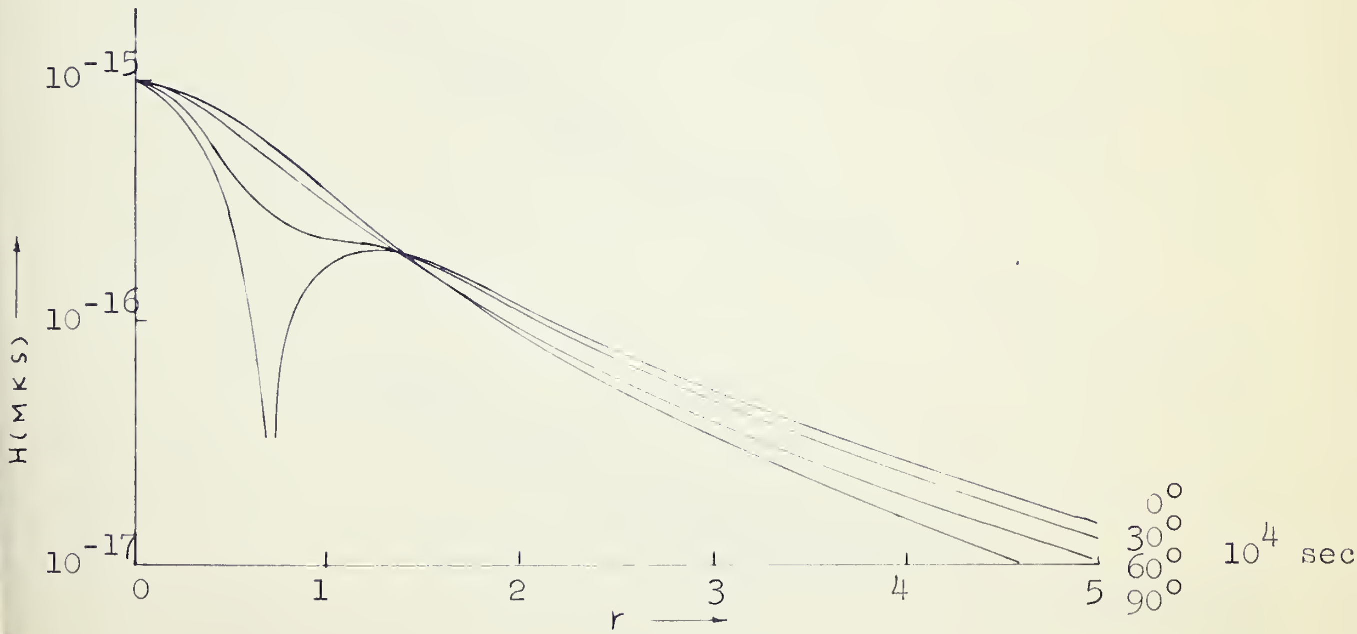


Figure 12. Space variation of Free space | H | of a H.M.D. at z = 0

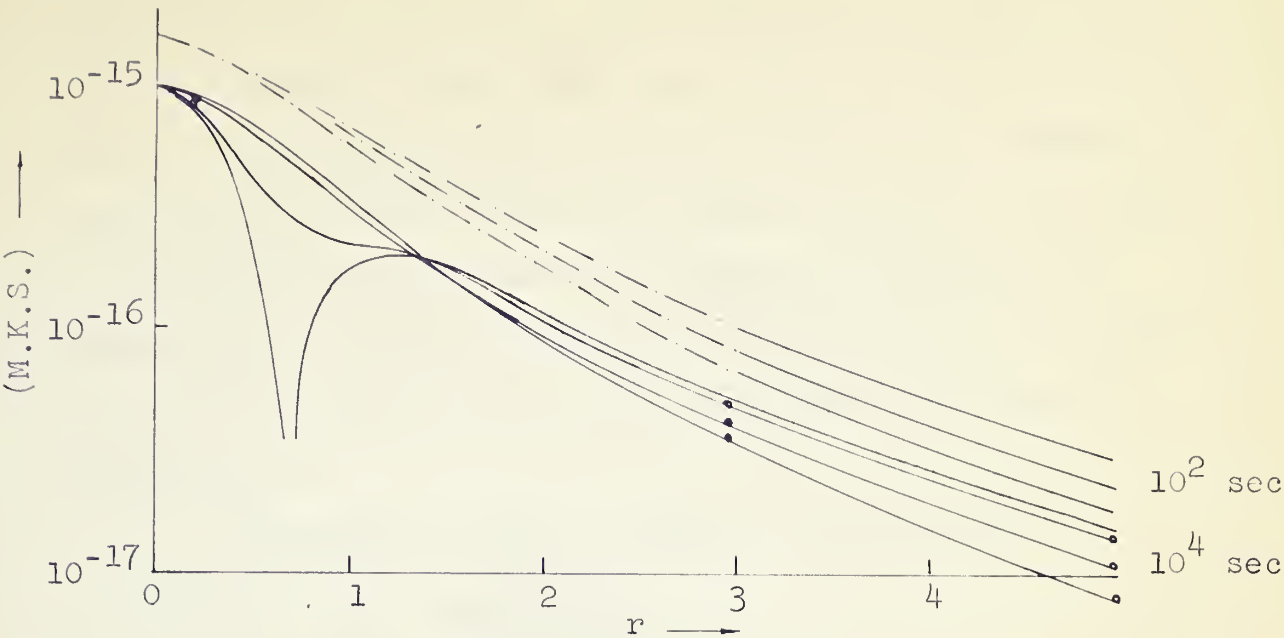


Figure 13. Superposition of Fig. 11 on Fig. 12.
Dots represent the lower curves in Fig. 11.

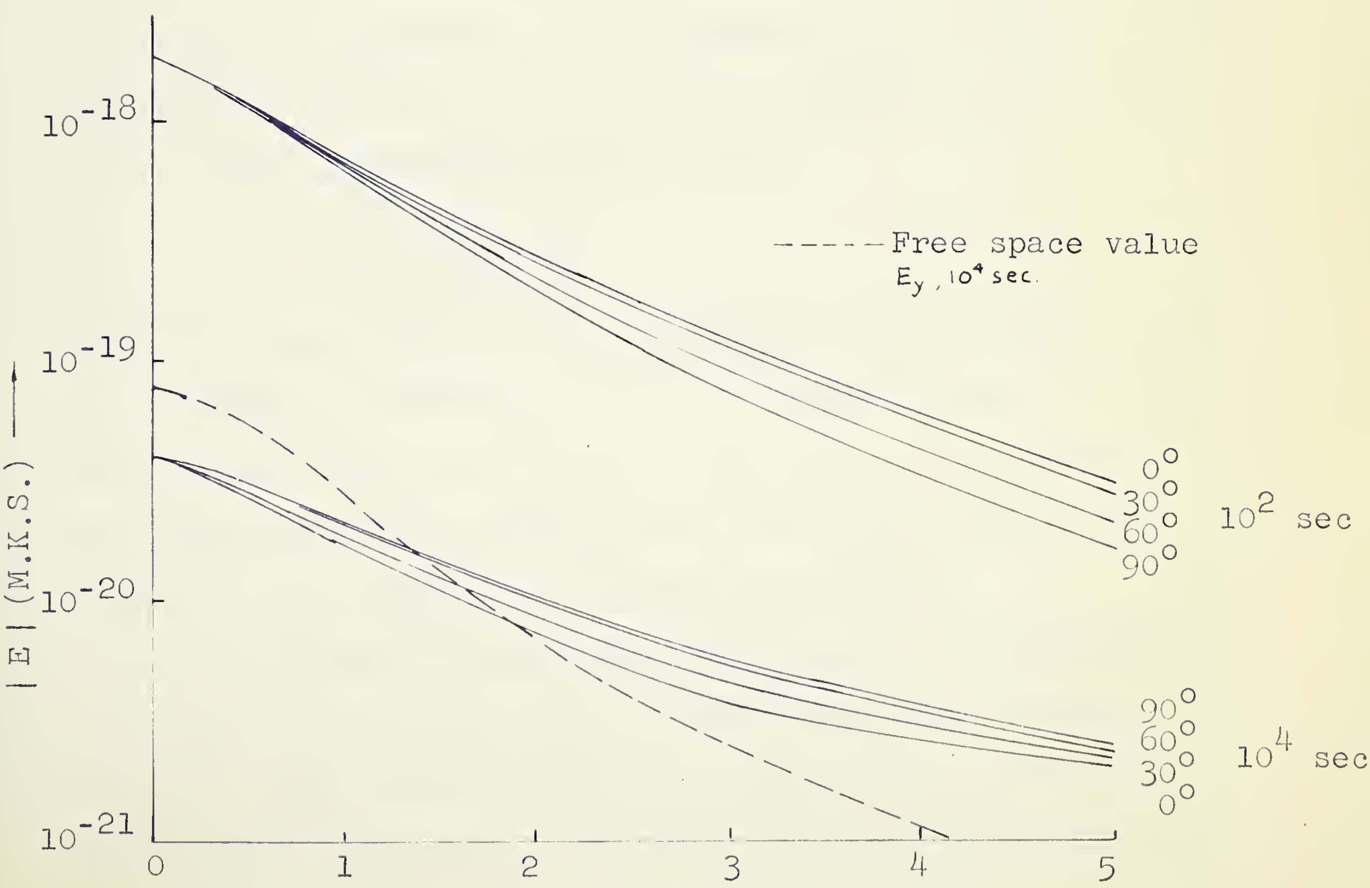


Figure 14. Space variation of horizontal | E | at z = 0

while those at $T = 100$ sec. have considerably larger values.

Figure 14 shows the space variation of the horizontal $|E|$ at two periods, 100 sec. and 10^4 sec., superimposed on which is the free space field at $T = 10^4$ sec. that is independent of φ. Obviously there is no correlation between the free space field and the total field whatsoever. However an explanation can be obtained from the following consideration:

As shown in case 2, section 2.2, we have

$$E_x = i\omega\mu_0 \frac{\partial}{\partial y} \Pi_z \quad ,$$

$$E_y = i\omega\mu_0 \left(\frac{\partial}{\partial z} \Pi_x - \frac{\partial}{\partial x} \Pi_z \right)$$

where Π_x is responsible for the primary field and part of the secondary field induced in the earth, and Π_z is entirely induced. Upon differentiation one finds

$$\frac{\partial}{\partial z} \Pi_x \simeq 0 \ .$$

In other words, the horizontal component of the primary E is almost entirely cancelled out by the induced field. Consequently the remaining horizontal component of the electric vector has only the induced portion left which should have little if any resemblance to the primary field.

As mentioned earlier, the E and H components upon the surface of the earth are not necessarily orthogonal. In fact, the angle between these two components is a function of space and the period T. Figure 15 shows the direction of

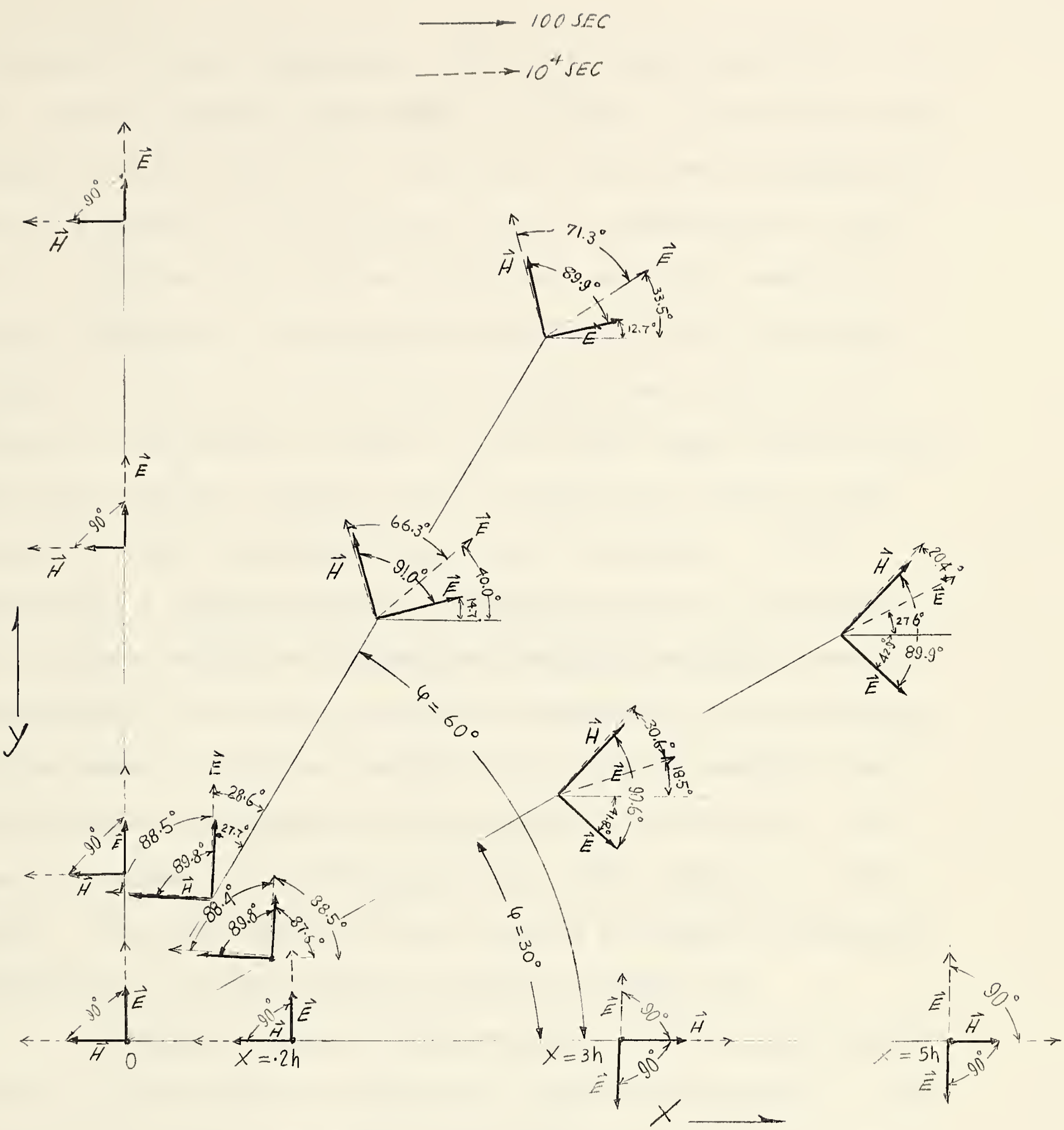


Figure 15. The horizontal $\vec{E}$ and $\vec{H}$ of an elevated horizontal magnetic dipole in the z = 0 plane for T = 100 sec. and 10^4 sec. Arrows indicate directions only. (Magnitudes are given in Appendix XI.)

26 pairs of such components. The solid lines are for T = 100 sec. and the dashed lines for $T = 10^4$ sec. It is very interesting to note that for T = 100 sec. all E and H components on the surface of the earth are nearly perpendicular while for $T = 10^4$ sec. the angles they form are quite sharp at large distances. One plausible explanation for the sharp angles is that at $T = 10^4$ sec. the earth has very little effect on the waves in spite of its fairly high conductivity, while the 100 sec. waves "see" the earth as a fairly good conductor with a conductivity of the top layer. If the earth were a highly conductive medium, waves of any angle of incidence would be transmitted perpendicularly downward. Consequently the E and H would be orthogonal on the surface of the earth. This may explain why at small periods E and H are almost orthogonal on the surface of the earth. At small r, waves of any frequency have small angles of incidence. Therefore their E and H should be nearly orthogonal regardless of their period as shown in Figure 15.

Figures 16a and 16b are plots of the angles between E and H on the earth's surface at $(3,30^o)$ and $(5,30^o)$. They show that E and H are nearly orthogonal up to $T \sim 1000$ sec. for r = 3 and up to $T \sim 2000$ sec. for r = 5. Mathematically this sudden change is due to the reversal of sign of E_y from negative to positive. (This is obviously shown in Fig. 15, at $\varphi = 0$.) That E_y has a positive sign means that the primary field dominates the secondary field in the y component of E. As T increases beyond this critical period, the earth

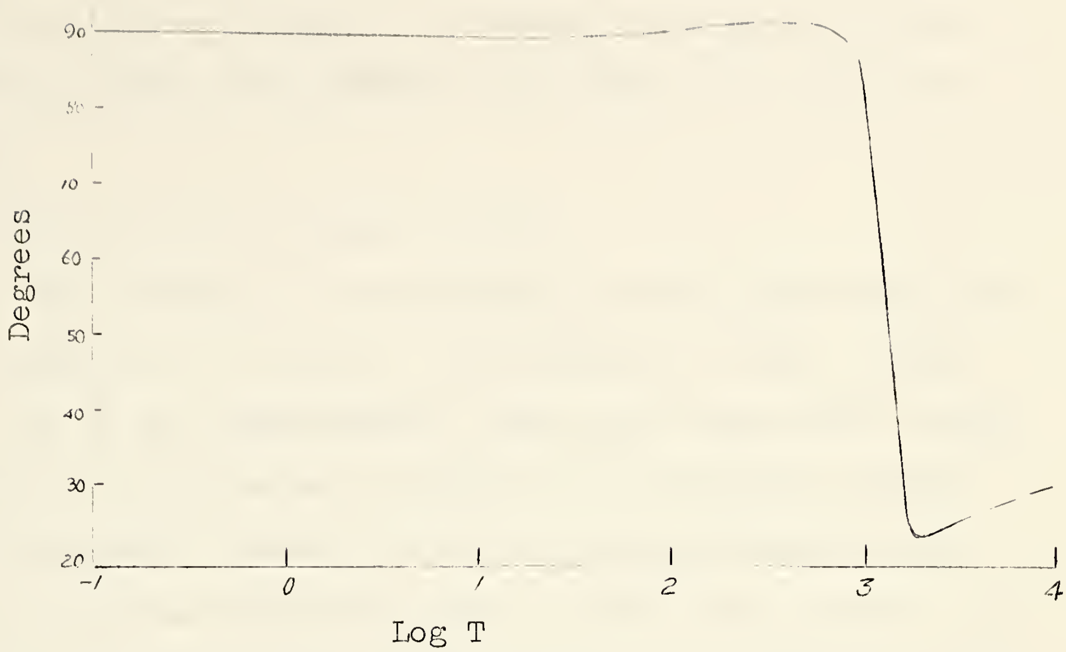


Figure 16a. Angles between the horizontal $\vec{E}$ and $\vec{H}$ on the earth surface of a H.M.D. $r = 3$, $\varphi = 30^{\circ}$

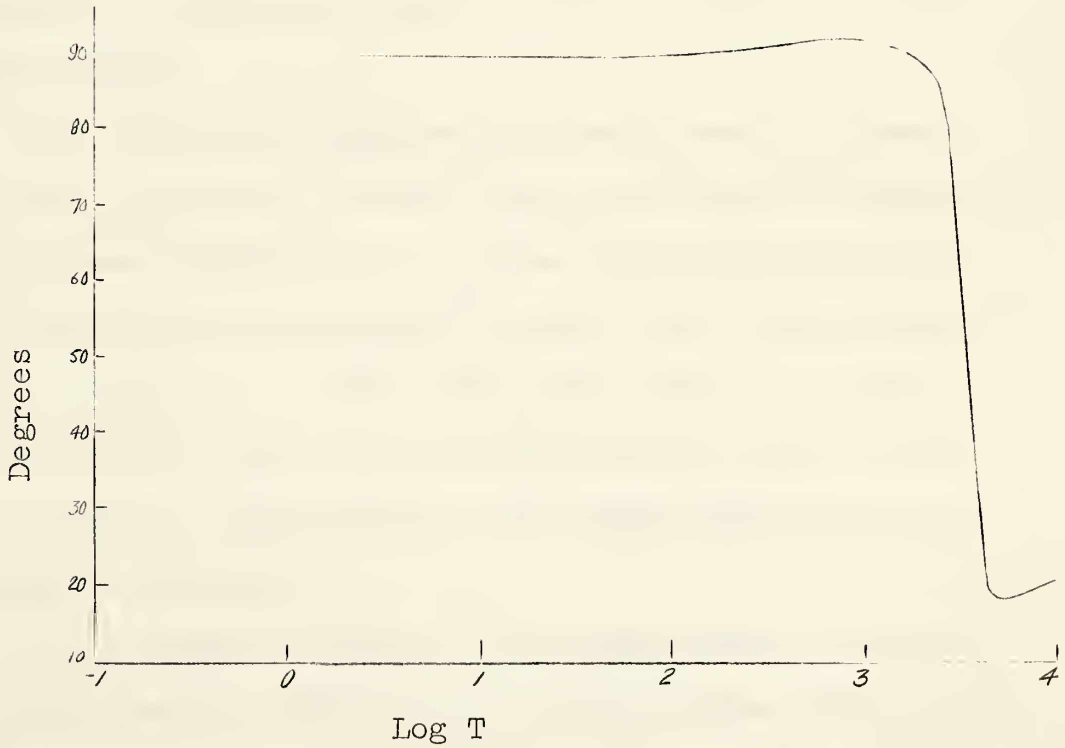


Figure 16b. Angles between the horizontal $\vec{E}$ and $\vec{H}$ on the earth surface of a H.M.D. $r = 5$, $\varphi = 30^{\circ}$

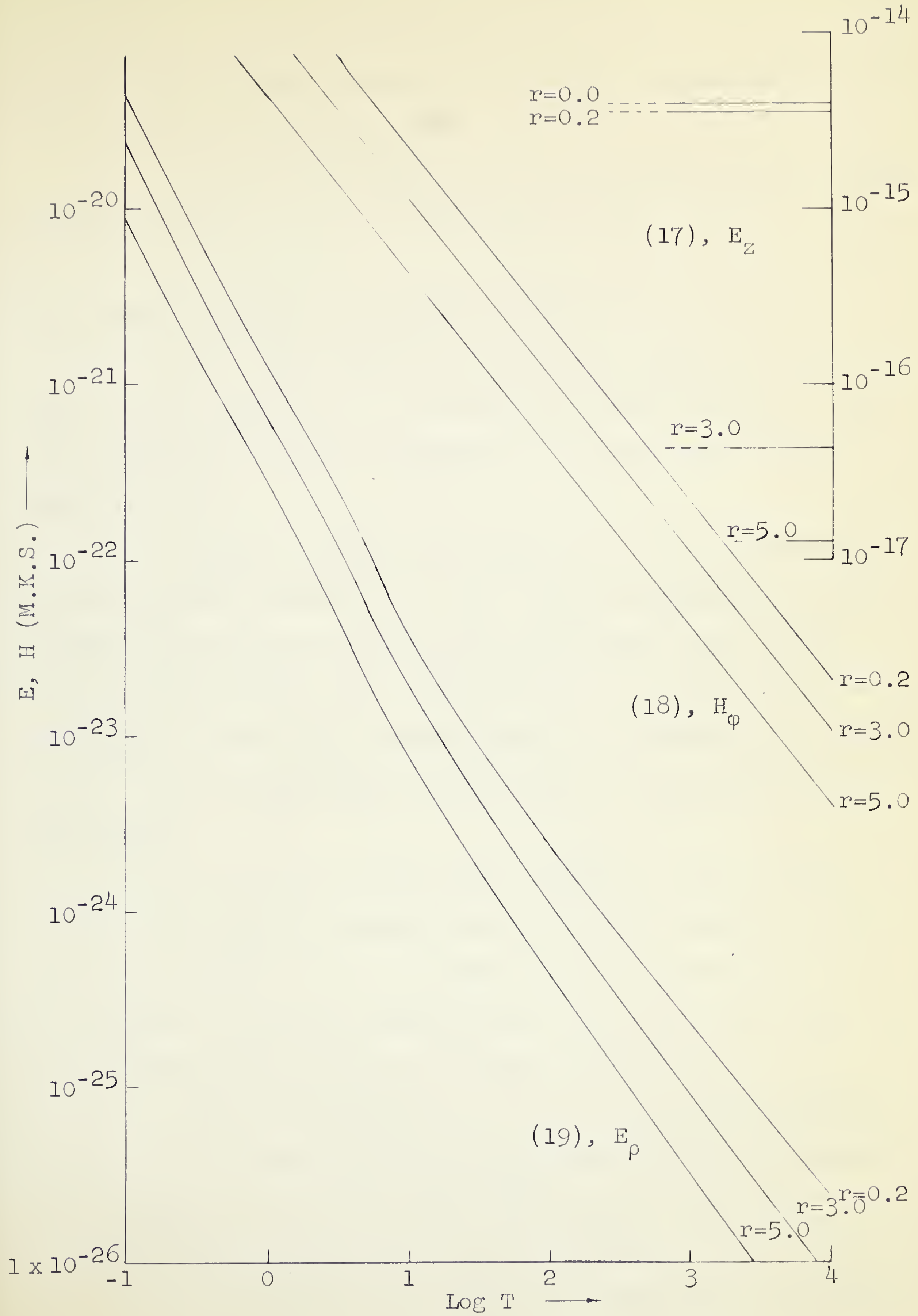
loses its influence rapidly. As shown in Figure 16 this interesting change occurs within the range of T $\sim$ 1000 to 5000 sec.

(C) Vertical electric dipole fields:-

The fields of the vertical electric dipole are plotted in Figures 17, 18 and 19. By equations (2-152, 2-153), both E_z and H_ρ are approximately twice the free space values as expected. E_z as shown in Figure 17 is entirely independent of frequency. However, this is just an approximation valid for only the frequency range in this study because the second term in (2-152) which is dependent on the frequency has been neglected. As pointed out on page 64, this term is important in comparison with the first in the kilocycle and higher ranges.

The space variation of E_z should have the characteristic shape of the H_z in the case of the vertical magnetic dipole as shown in Figure 8. E_z also has a discontinuity in the log-log plot as commented on page 104. This discontinuity also occurs at $r \sim \sqrt{2}$. The second term in (2-152), if included, would shift the discontinuity a little to the right in Figure 8. This shift becomes more appreciable as the frequency increases.

E_ρ as shown in Figure 19 is many orders of magnitude smaller than E_z. This is the obvious effect of the presence of a conducting earth. As we have seen, E_z has been doubled due to the conductive medium. On the contrary, the



Figures 17, 18, 19. E and H of a V.E.D.

primary E_ρ is almost cancelled out by the induced field. This is clear from equation (2-134).

By equation (2-153) H_φ of a vertical electric dipole is approximately twice the free space value.

(D) Horizontal Electric Dipole Fields:-

As in the case of the horizontal magnetic dipole, the field strength at r = 0 cannot be computed directly from the expressions given in Chapter II, but they are given in Appendix II.

Figure 20 shows the plots of x, y and z components of the electric field at $\varphi = 30^\circ$. E_z is independent of frequency and twice the value of the free space field within the frequency range under consideration. E_y components appear as straight lines because they are inversely proportional to $\sqrt{T}$. The E_x components reverse sign at frequencies dependent upon r.

It is worth noting that at small r, E_x is about 2 order of magnitude larger than E_y; in other words, the horizontal electric vector is almost in the x direction. As r increases, E_x and E_y approach each other and, at r = 5, E_x is nearly equal to E_y at the short period end.

Figure 21 are plots of the surface magnetic components. At the short period end H_y is the dominant component and is equal to twice its free space value. The other two components gain significance at long periods. At T > 1000 sec., for r = 3 and 5, $|H_y|$ decreases steeply and a sign re-

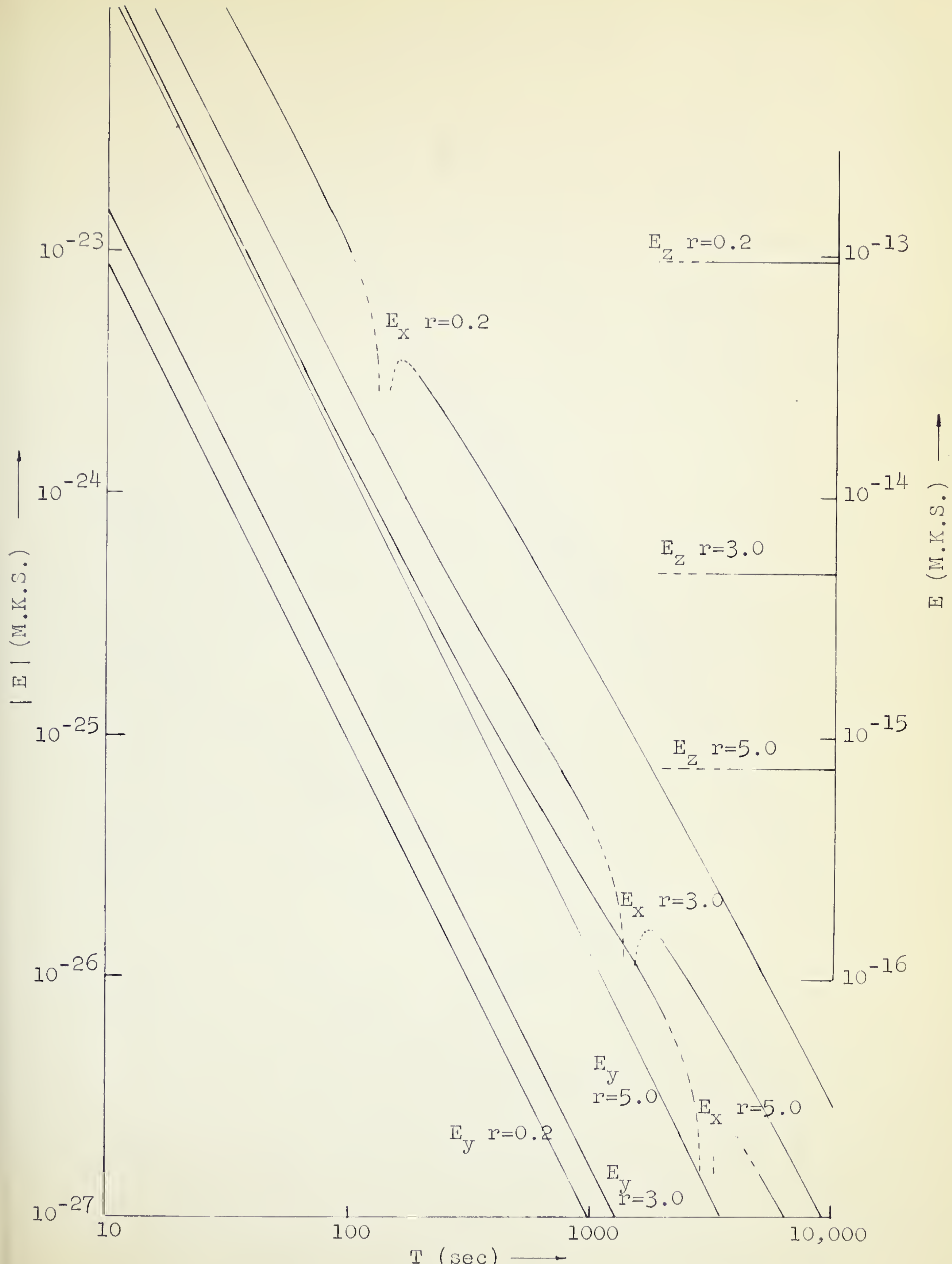


Figure 20. Electric fields of a horizontal electric dipole

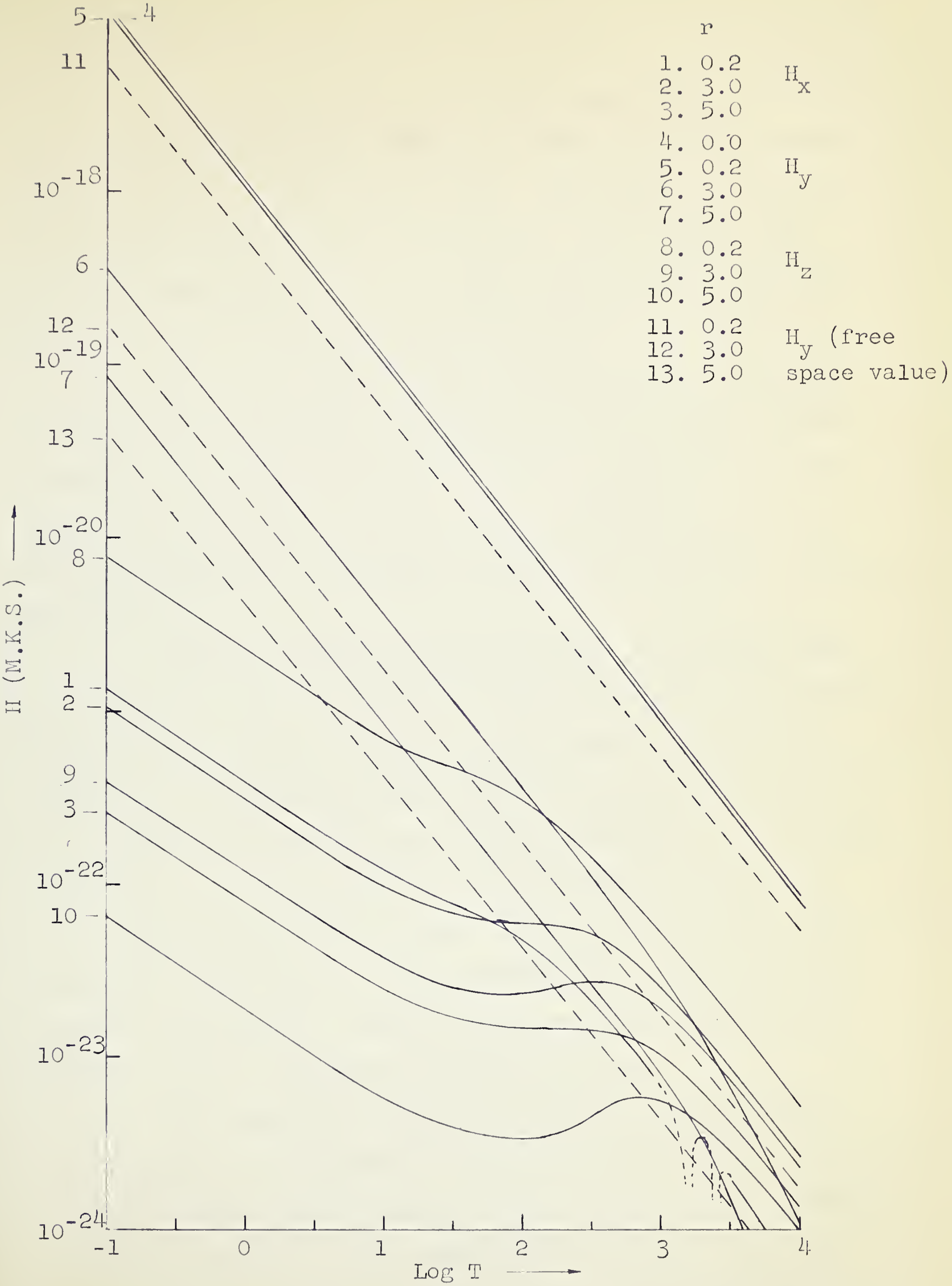


Figure 21. Magnetic fields of a H.E.D. at $z = 0$, $\varphi = 30^{\circ}$

versal could be expected at still longer periods. In fact a sign reversal does occur for H_y at T = 5000 sec., r = 3, and at $T = 10^4$ sec., r = 5, and $\varphi = 90^\circ$. (See table in Appendix X) By comparing the values for H_y at $\varphi = 90^\circ$ in the table one also finds that at r = .2, H_y is negative as is the free space field at all frequencies. However, at r = 3 and 5, H_y is positive at short periods and changes sign at long periods. Obviously at a particular period H_y vanishes at some r which depends upon φ. Since this phenomenon does not occur in free space, detailed study of this aspect of the problem can be achieved only when more values for H_y as functions of r are available.

Figure 22 shows how H_y may vanish and reverse sign at different r and T. The solid lines represent interpolated values between computed points and the dashed lines just indicate the possible progression of the discontinuity in T and r. H_y possesses the same sign as the free space value between r = 0 and r = 5 at $T = 10^4$ sec., but reverses sign between r = 0 and 3 for shorter periods. This illustrates that the influence of the earth is far more reaching at short periods than at long periods. Exactly the same effect has been observed on E_y of a horizontal magnetic dipole.

The fields of a horizontal static dipole above a good conductor (corresponding to $T \rightarrow \infty$) is very simple, i.e. only E_z is twice the free space field, and all other electric components are zero. This limiting value of the field can be obtained from the equations in Chapter II by letting $T \rightarrow \infty$.

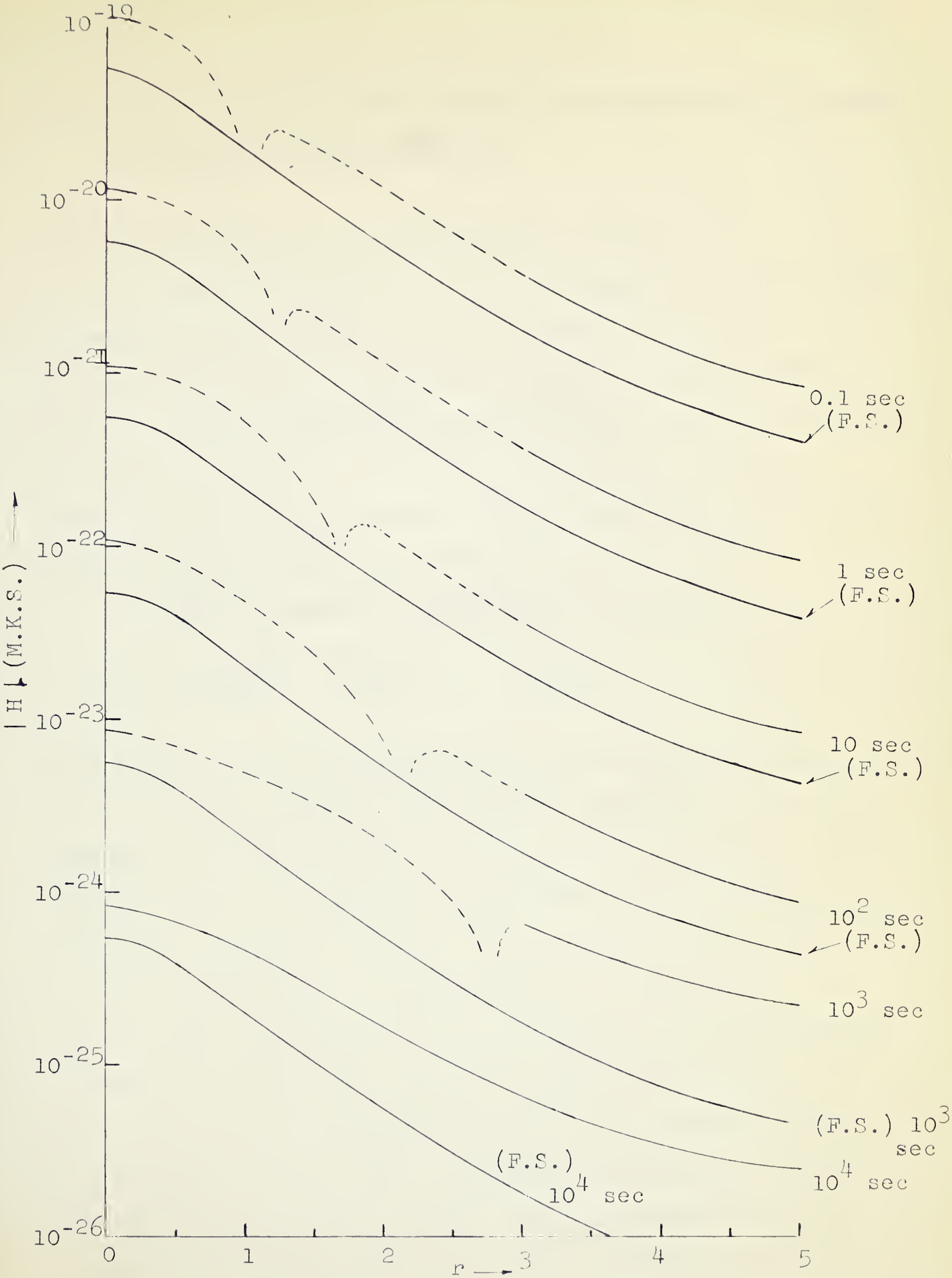


Figure 22. $|H_y|$ of a H.E.D. in free space and in presence of the earth at $z = 0$, $\varphi = 90^\circ$

4.2 Study of Apparent Resistivities of the Earth in Connection with Magnetotelluric Theories

(A) Characteristics of the Resistivity Curves:-

Two of the three objectives suggested for this thesis in Chapter I have been attained. Now with the computed results available we are going to investigate various magnetotelluric theories proposed by various authors which are briefly outlined in Chapter I. It is more appropriate, however, to start this section by defining the term "apparent resistivity" which is freely used in this thesis.

Let the apparent resistivity be ρ_a, then

$$\rho_a = \frac{T}{5} \cdot \left(\frac{10^4}{4\pi}\right)^2 \cdot \left|\frac{E_{/\!/}}{H_{\perp}}\right|^2 \qquad \text{(ohm-m)} \qquad (4\text{-}1)$$

where T in sec. is the period of the electromagnetic field whose orthogonal electric and magnetic components (in the horizontal plane) are designated by $E_{/\!/}$ and $H_{\perp}$ in M.K.S. units. Therefore ρ_a is a variable dependent upon the frequency and the nature of the wave whose E and H components are used, in contrast to the actual resistivities of a medium which, to a first degree approximation, is invariant at low frequencies. It should be noted that ρ_a can be uniquely defined only when the electric vector is perpendicular to the magnetic vector in the plane on which field strengths are computed. Therefore, for the horizontal dipoles under consideration, only the apparent resistivities at $\varphi = 0^{\circ}$ and 90° will be fully

discussed. However, ρ_a thus computed for $\varphi = 30^{\circ}$ and 60° together with those at $\varphi = 0, 90^{\circ}$ are given in Appendix XII.

Equation (4-1) has also been used to compute apparent resistivity curves (Figure 23) for Price's theory. The E/H ratio for a 2-layered earth has been computed from the following equations (Price 1962):

$$\frac{E_{/\!/}}{H_{/\!/}} = i\omega \, \frac{\theta + \nu + (\theta - \nu)e^{-2\theta D}}{\theta\left\{ \theta + \nu - (\theta - \nu)e^{-2\theta D}\right\}} \tag{4-2}$$

where $\theta^2 = \nu^2 + 4\pi i\omega\sigma$, σ being the conductivity of the top layer and ν a separation constant that assumes various values corresponding to sources of different dimensions. However, it should be noted that (4-2) is in e.m.u. and is for a 2-layered model with an infinitely resistive substratum.

Two Cagniard curves have been computed for $\sigma_1 = .2$ (mho-m^{-1}), $\sigma_2 = .002$ (mho-m^{-1}) and $\sigma_2 = 0$, (Figure 23). The second curve is identical to Price's curve for $\nu \to 0$, an infinitesimal ν corresponding to a source of infinitely large dimensions, thereby radiating plane electromagnetic waves when observed at finite distances as assumed by Cagniard (1953).

It is noted that with ρ_1 fixed, decreasing ρ_2 results in decreasing Cagniard's apparent resistivities. If ρ_2 is reduced to 500 Ω-m from an infinitely large value, Price's curve may also drop a little, though no careful quantitative analysis has been attempted. This will be discussed further in connection with the apparent resistivity curves computed from dipole fields. The most striking difference

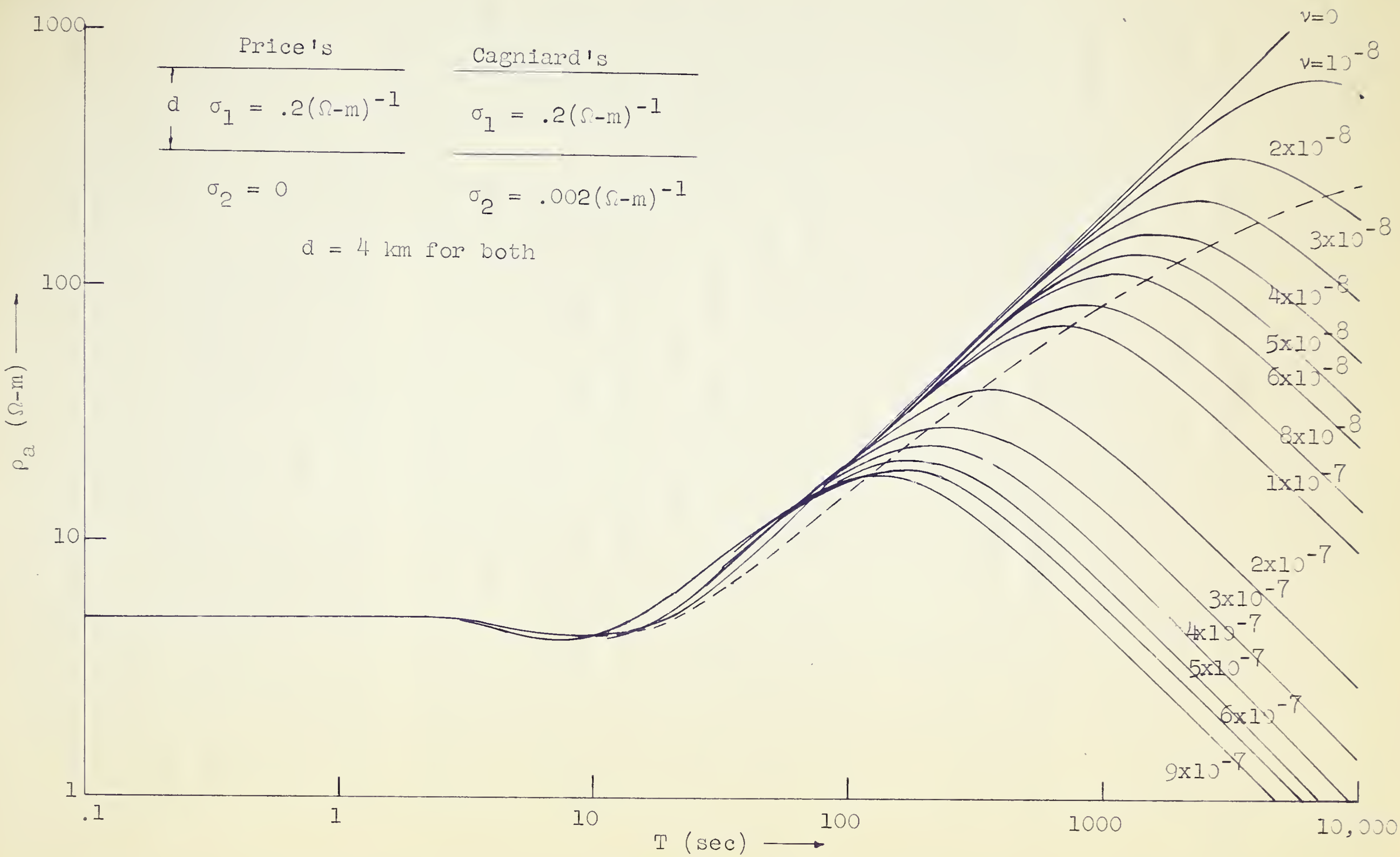


Figure 23. Cagniard's and Price's apparent resistivity curves. $\nu = 0$ corresponds to Cagniard's curve for the same geological configuration.

between Cagniard's and Price's curves is that as the period increases, Cagniard's curves approach the resistivity of the substratum as a limit, while Price's curves descend steeply. This steep descent is of great significance and can best be discussed with the dipole cases.

Figure 24 shows plots of the apparent resistivities computed from the vertical magnetic dipole fields. Superimposed upon them are Cagniard's curves and a few of Price's curves. All curves are identical up to $T \sim 7$ sec. At $T \lesssim 2.5$ sec., the apparent resistivities for all cases are equal to the resistivity of the top layer. This is a well-known fact for Cagniard's theory and not at all surprising for the dipole fields either, because at $T \sim 2.5$ sec. the skin depth is about 1.1 km. while the upper layer is 4 km. thick. All these waves "see" a virtually homogeneous earth with the conductivity of the upper layer. ρ_a with the vertical magnetic dipole attains maxima at various periods which depend upon r: $T = 200$ sec., $r = .2$; $T = 2000$ sec., $r = 3$; $T = 6000$ sec., $r = 5$. As T increases beyond the maximum all ρ_a decrease.

It is of great interest to note that in Figure 6 at $r = 0.2$, E_φ is about half of the free space value at $T = 100$ sec., but nearly equal to it at $T = 1000$ sec. At 1000 sec., E_φ is approximately 3/4 of the free space value at $r = 3$ and only 1/3 at $r = 5$, but at 10^4 sec. E_φ is very close to the free space value at both r. All these strongly indicate one fact. That is that all the maxima of ρ_a in

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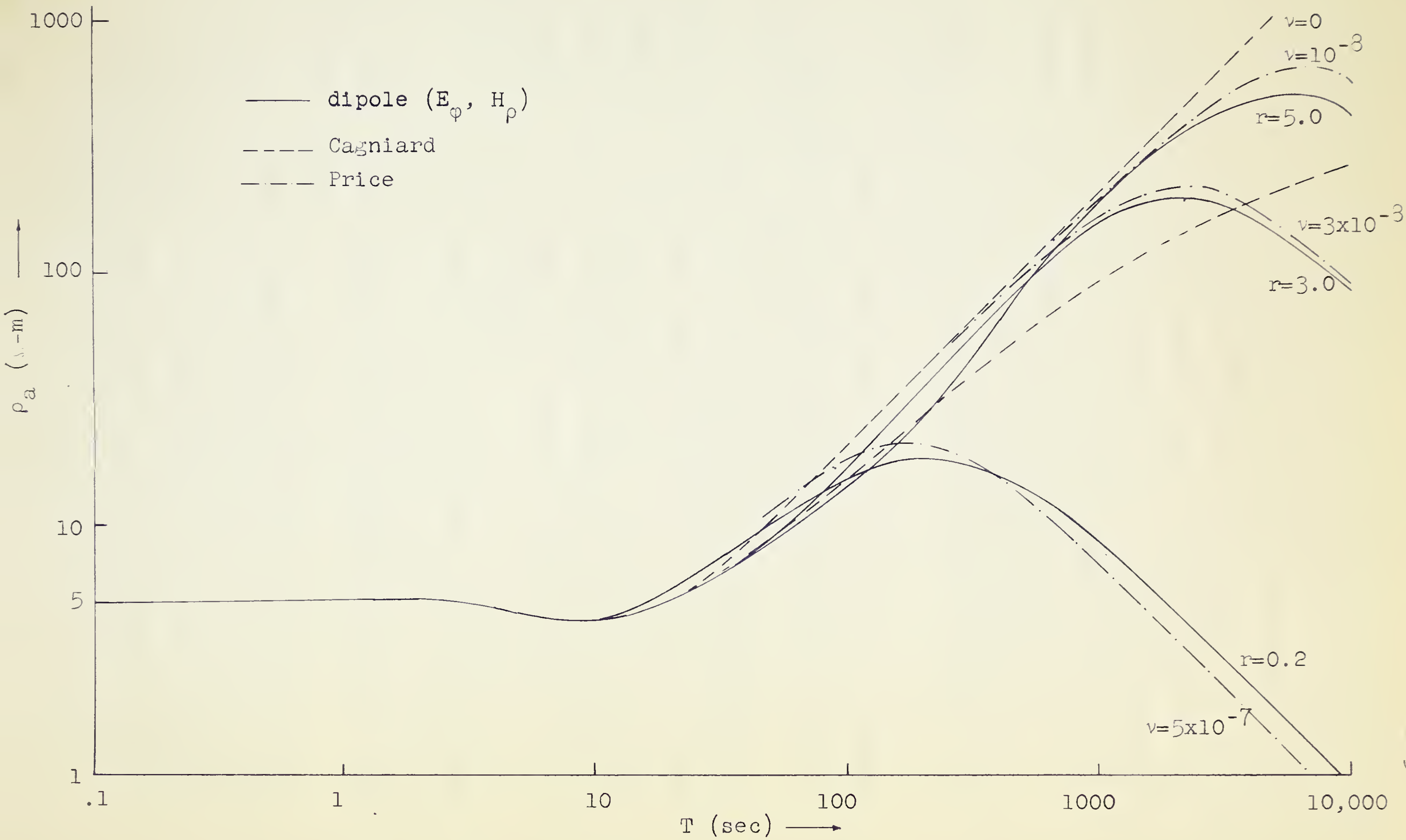

Figure 24. Apparent resistivity curves for a V.M.D.

Figure 24 occur at the periods when the conductivity of the earth starts losing its influence on the incident waves. As T increases ρ_a should approach zero. This is expected for the magnetic dipoles, because as $T \to \infty$, the magnetic dipole becomes a static dipole or a permanent magnet which has no electric field. Consequently E/H should be zero.

The whole argument is strongly supported by the ρ_a computed from the horizontal magnetic dipole which will be discussed very shortly.

Figure 24 indicates that at T > 20 sec. attempts to approximate the vertical magnetic dipole field by plane wave field in computing ρ_a will be futile.

Figure 25a, b are plots of ρ_a computed from the fields of a horizontal magnetic dipole at r = 0, .2, 3 and 5 along the x and y axes ($\varphi = 0, 90^\circ$). As pointed out before, E and H vectors on the earth's surface are not in general orthogonal off the axes. ρ_a computed in these regions will be given a special description.

It was pointed out earlier that the maxima signify the periods at which the earth starts losing its influence on the waves. This argument is also strongly supported by Figures 25 a and b.

Figure 25 shows that the maxima occur at T ~ 350 sec. for r = 0 and 0.2, T ~ 700 sec. for r = 3 and T ~ 1500 sec. for r = 5.0. If we study Figure 10 we find that these periods are very close to where E_y start decreasing rapidly and where H_x approach the free space values which are the

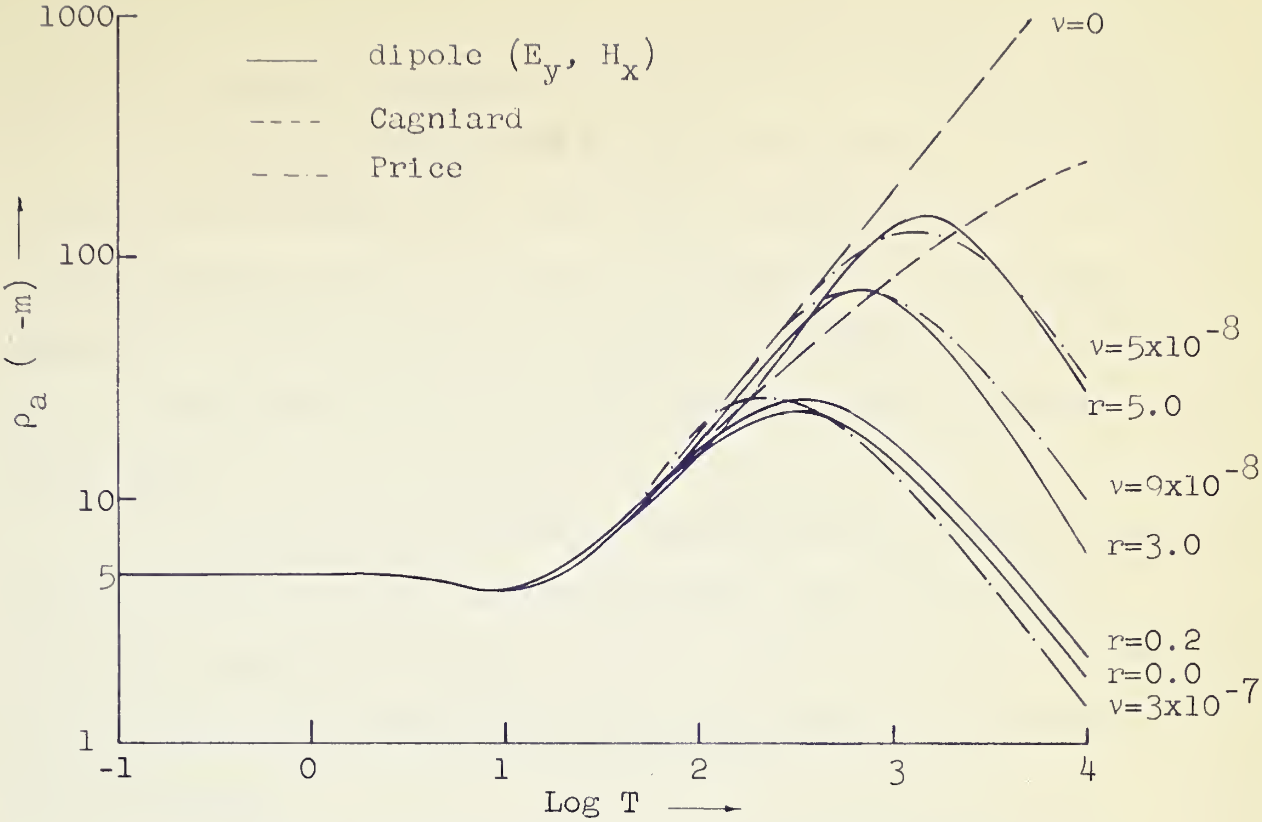

Figure 25a. Apparent resistivity curves for a H.M.D. at $\varphi = 0$

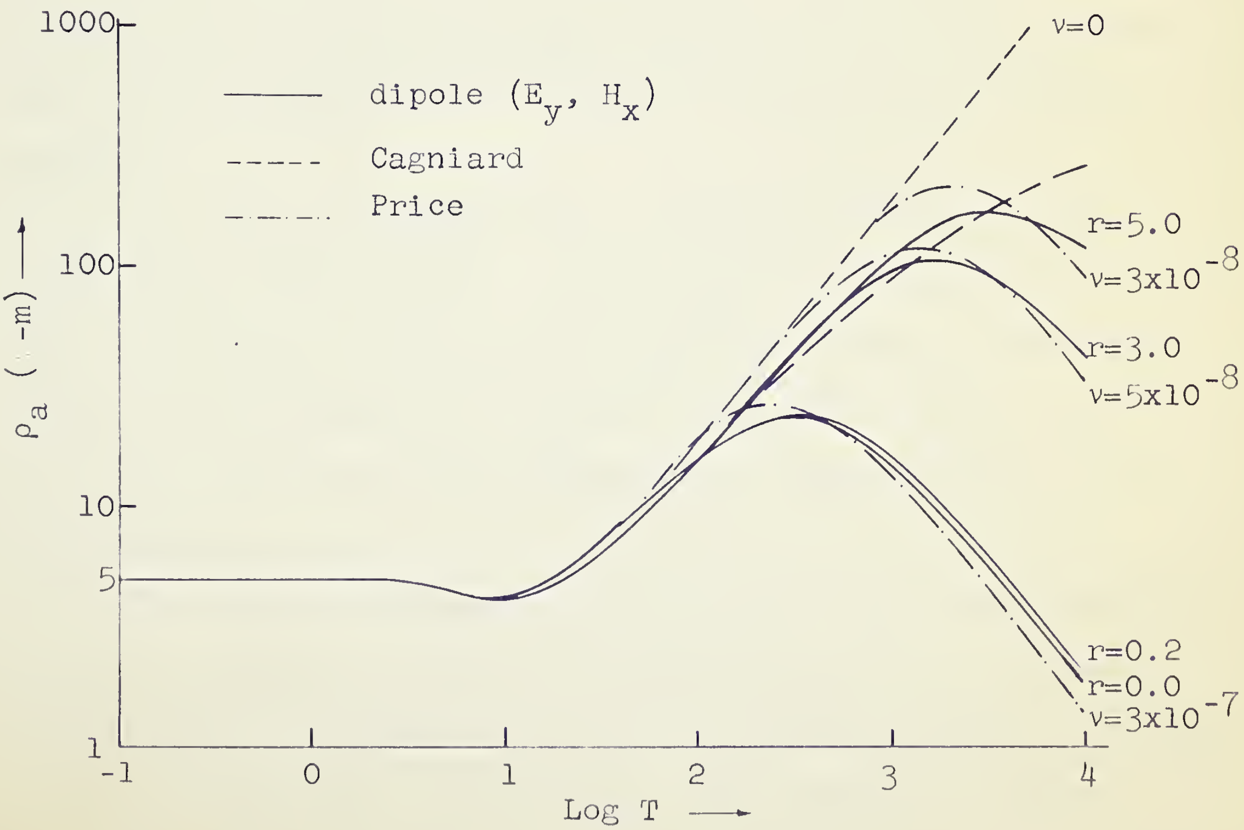

Figure 25b. Apparent resistivity curves for a H.M.D. at $\varphi = 90^{\circ}$

values the magnetic components attain at T $\sim 10^4$ sec. However, it should be noted that Figure 10 is for $\varphi = 30^\circ$ though these field strengths are very close to those for $\varphi = 0$. This can be checked with the tables in Appendix X. If the same comparison is made between Figure 25b and Figure 10 with the help of Appendix X, one will find that the above argument also holds.

One obvious difference between Figure 25a and b is that ρ_a computed along the x-axis drops much more steeply than that computed along the y-axis. This is because E_y decreases much more rapidly at the x-axis than at the y-axis as T increases.

Cagniard's curve is not a good approximation for T > 100 sec. at large r. At r = 0 and 0.2, the ρ_a for the dipole starts deviating from Cagniard's values at T = 7 sec. Note that the deviation at T $\sim$ 10 sec. is also present in Price's curves.

Figure 26 shows the ρ_a computed from E_x/H_y and E_y/H_x at $\varphi = 30^\circ$ and 60°. It is interesting to note that E_x/H_y is entirely independent of angular distances from the x-axis, even though $E_x = 0$ at $\varphi = 0$ and 90°. Since at 30° and 60°, E and H are not orthogonal at large periods, ρ_a is not defined.

Figure 27 shows ρ_a computed for a vertical electric dipole. Obviously these ever increasing ρ_a with increasing period have no resemblance at all to those discussed previously except in the short period range. This result is somehow

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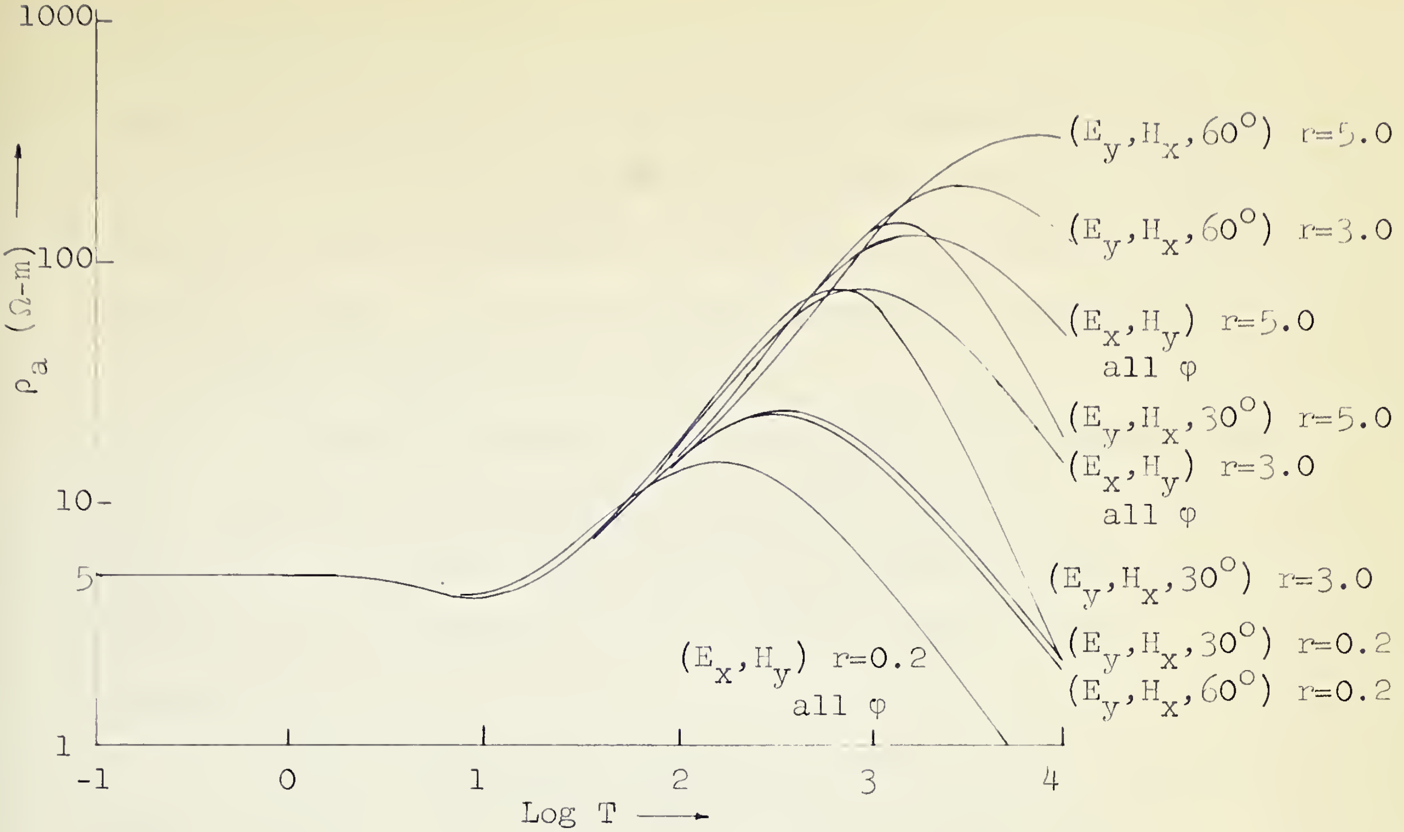

Figure 26. Apparent resistivty curves for a H.M.D.

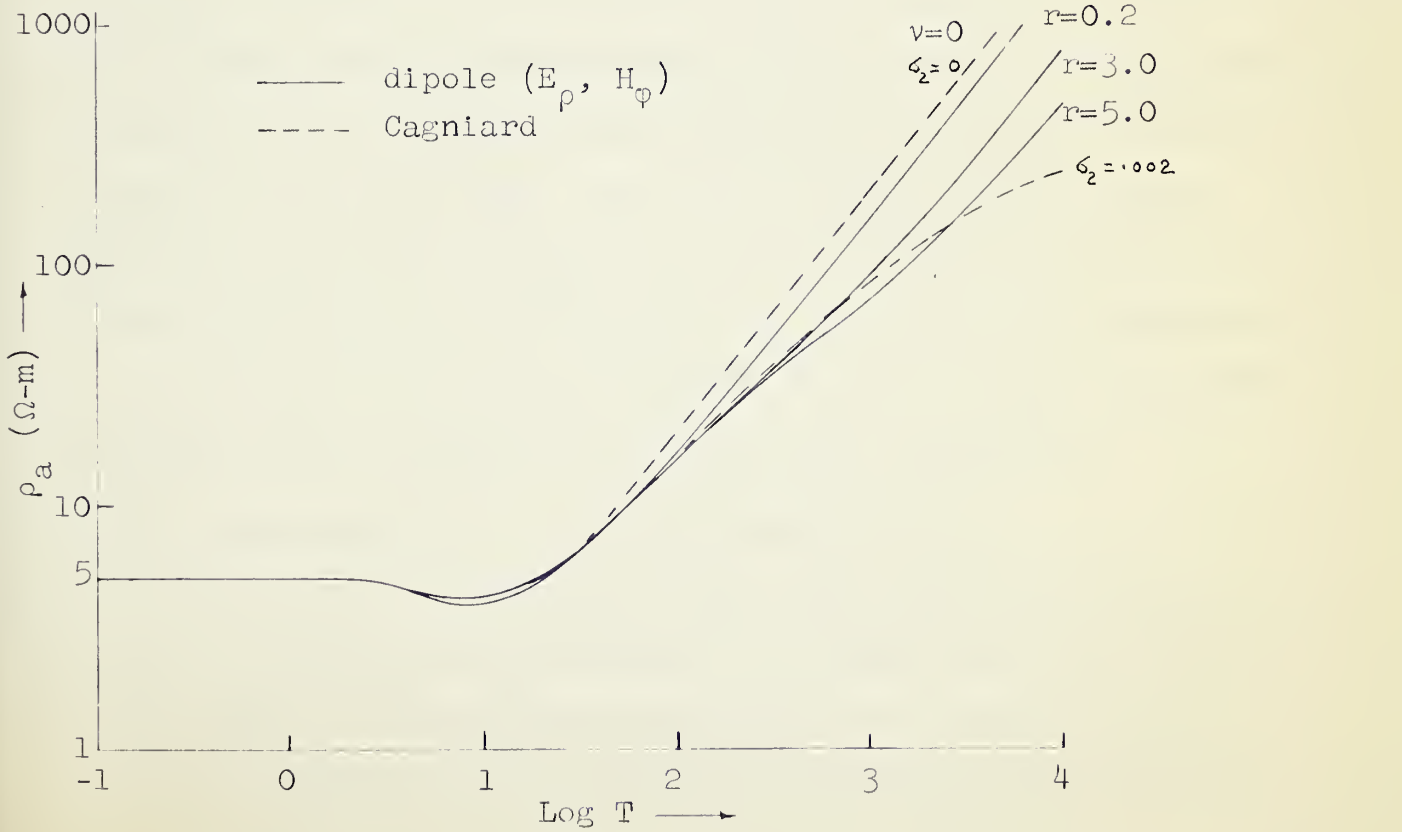

Figure 27. Apparent resistivity curves for a V.E.D.

expected of an electric dipole. In fact the manner in which the resistivity curve changes as T increases depends on the comparative rate of change of the horizontal electric and magnetic fields. In this case E/H is almost a constant at long periods (Appendix XII, V.E.D.)

Figure 28 shows a plot of ρ_a for the horizontal dipole. Again this is entirely different from all the cases discussed previously. This amazing difference between the vertical and horizontal electric dipoles needs a close examination.

Since physically the horizontal electric fields of both a vertical and a horizontal electric dipole tend to cancel out on the surface of a conductor, the striking difference between the ρ_a computed in each case must be mainly due to the rate of cancellation as T increases. A close examination of the original equations given in Chapter II shows this is indeed the case. For the vertical electric dipole both E_ρ and H_φ vary as ω and for the horizontal electric dipole E_x and E_y vary as ω^2, while H_x, H_y vary as ω. Therefore E_x and E_y of the horizontal dipole sources decrease much more rapidly as T increases than do all other components.

(B) Significance of ν in Price's Formulation:-

Price in his paper (1962) had clearly pointed out that ν, the separation constant in the wave equation, is the wave number. He further proposed $2\pi/\nu$ as a measure of the linear dimension of the radiating source, and concluded that

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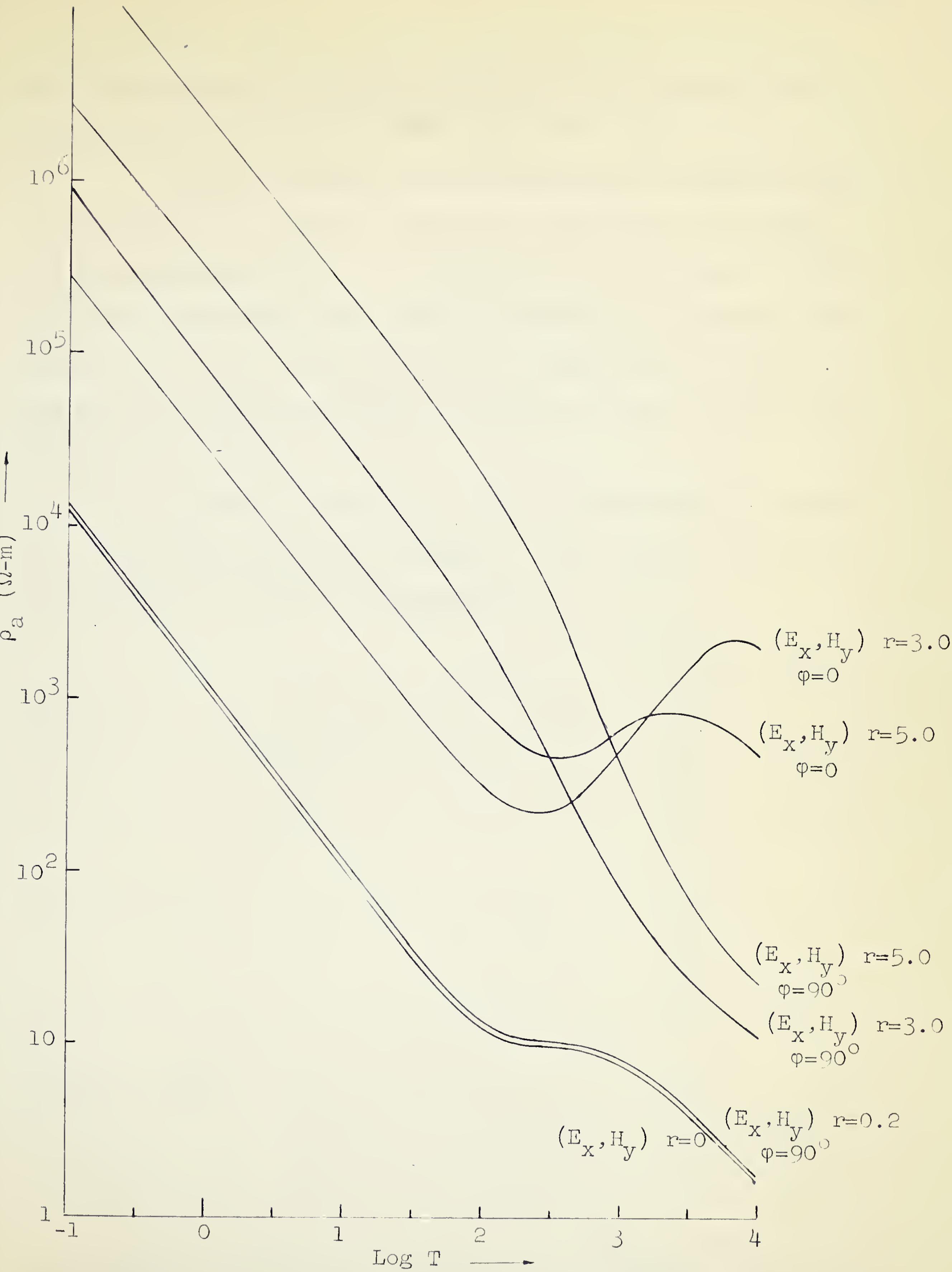

Figure 28. Apparent resistivity curves for a H.E.D.

for magnetotelluric work the values of ν of interest would range from 1.57×10^{-9} cm^{-1} to 1.57×10^{-7} cm^{-1}.

Price's concept of ν is generally confirmed in Figures 24 and 25. Whatever estimates appear below are only rough approximations. As pointed out earlier, Price's curves have been computed from a slightly different geological formation, i.e. $\sigma_1 = .2$, $\sigma_2 = 0$. It is expected that Price's curves would decrease towards Cagniard's second curve if the same σ_2 were used.

Figures 24 and 25a, b show the approximate values of ν corresponding to ρ_a for each r. In Figures 24 and 25 we have the following correspondence:

	r	ν (cm^{-1})	h (cm)	$1/h\nu$
V.M.D.	0.2	4.5×10^{-7}	10^7	.2
	3.0	$.35 \times 10^{-7}$	10^7	2.9
	5.0	$.12 \times 10^{-7}$	10^7	8.3
H.M.D. $\varphi = 0^\circ$	0.2	3×10^{-7}	10^7	.3
	3.0	$.9 \times 10^{-7}$	10^7	1.1
	5.0	$.5 \times 10^{-7}$	10^7	2.0
H.M.D. $\varphi = 90^\circ$	0.2	3×10^{-7}	10^7	.3
	3.0	$.4 \times 10^{-7}$	10^7	2.5
	5.0	$.3 \times 10^{-7}$	10^7	3.3

The situation is much too complicated to attempt a meaningful

correlation between ν and r. However, this simple correlation is quite consistent with Price's concepting of ν, since either increasing r or decreasing ν will give rise to plane wave approximation.

(C) Comparison with Wait's Formulation:-

Wait has formulated the surface intrinsic impedance for a line current and a vertical electric dipole (1953, 1962) over a stratified conductor by analogy to plane waves at complex angles of incidence. Extensive computation for a related parameter Q in the following expression has been done for various values of β (Jackson et al, 1962):

$$z_1 = - \left.\frac{E_x}{H_y}\right|_{z=0} = \left(\frac{i\mu_0\omega}{\sigma_1}\right)^{1/2} \frac{Q}{(1 - i\beta)^{1/2}}$$

where $$Q = \frac{u_1 + u_2 \tanh u_1 h}{u_2 + u_1 \tanh u_1 h} ,$$

$$\beta = \frac{\lambda^2}{\sigma_1 \mu_0 \omega} ,$$

$$u_j = (\lambda^2 + i\sigma_j\mu_0\omega)^{1/2} .$$

Since Wait uses $e^{+i\omega t}$ instead of $e^{-i\omega t}$, u_j is equivalent to p_j in the formulation in this thesis.

Wait has identified $(i\lambda)$ with $(k \sin\theta)$, k being the propagation constant in the air and θ being the complex angle of incidence. $\lambda = 0$ (or more explicitly $\theta = 0$) corresponds to a normally incident plane wave as assumed by Cagniard.

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If λ is other than zero, θ is complex and corresponds to non-plane waves arising from real sources.

In fact Price's formulation is just another approach to Wait's. In order to compare Wait's result with the dipole results, one can either use the E/H ratio given in Appendix XII to compute a quantity equivalent to Q from the equation for z_1, or use z_1 to compute the apparent resistivity curves. A preliminary study shows that for a very small value of λ, the equivalent Q computed from the dipole results is equivalent to Wait's at short periods, but departs from it considerably at long periods. It is worth pointing out that the parameter λ has the same significance as ν discussed in the previous sub-section.

Wait concluded that one should be very careful in the interpretation of experimental data on the surface impedance when the source field is not known. A similar conclusion is reached in this study.

V. CONCLUSION AND SUGGESTION FOR FURTHER WORK

The foregoing study can be categorized into three interrelated sections, namely the mathematical treatment of the dipole problems, computation of dipole fields on the surface of the earth, and finally the study of magnetotelluric theories in the light of these computations.

Since the exact solutions have been obtained for all four proposed problems, little is left to be said about them, unless one attempts an analytic solution for the complex integral.

On the other hand the computation of the fields is far from complete. The most obvious gap is in the spatial variation of the various components of these fields. As shown in the numerous graphs presented, frequently there is a discontinuity in a log-log plot for various reasons. It would be very interesting to see how the fields behave near the discontinuity. It would also be of great interest to complete the pictures of near fields, within say, $r = 5.0$, to see how the influence of the earth breaks down at various frequencies and distances.

Since the study in this thesis has been limited to only one geological configuration, nothing conclusive can yet be said about other earth models than the one just studied,

in particular in connection with the apparent resistivity curves. Therefore it would indeed be very desirable to study more models of some different resistivity combinations in order to complete a general picture for a 2-layered earth.

The study of the magnetotelluric theories has been concentrated on the comparison of the apparent resistivity curves. It must be pointed out here that the study of phase differences versus the periods of the E and H components has not been carried out in this thesis, though the essentials for such a study are provided. In fact, the phase angles for the surface E and H components for the horizontal dipoles are given in Appendix XI. A survey study of these results indicate that for most of the cases, both the horizontal E and H components on the surface of the earth are nearly linearly polarized. (i.e., the phase differences are very small.) However only more detailed studies can warrant a more definite conclusion.

Though interesting results have been obtained corresponding to Price's formulation little has been said about the source effects in connection with observation data. The thesis will conclude with a supplementary discussion in this respect.

First we shall have a look at the observational results obtained by the geophysics group of the University of Alberta. Up to the present, no large amount of data has been processed to confirm the validity of Cagniard's theory at the long period end or otherwise. However there are some indica-

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tions that this theory may not be adequate to explain the long period phenomena as pointed out by Hasegawa in his thesis (1962). The large scatter observed also seems to require more complex sources.

Wiese (1962) has published some observation results in the form of apparent resistivity versus period. The shape of Wiese's curves does not suggest that they can be easily fitted by Cagniard's two or three layered curves. Wiese's curves are characterized by fairly large curvatures that Cagniard's curves do not have, and by large scatter. At long periods, all Wiese's curves decrease with period. At these periods the wavelengths are enormous and the plane wave approximation can hardly be expected to hold. All Wiese's results in this paper seem to indicate that Cagniard's assumption of plane incident waves needs modification, in particular at the long period end. In both sets of observations, scatter appears to be larger than one would predict on the basis of geological complexity and instrument error.

Bomke (1962) reported that in his observation there was strong indication that, for micropulsations in the 1 cps range, the ratio of E/H was approximately 10^5 ohm and in the .1 - .01 cps range, E/H is of the order of 10 ohms. (Note his ratios are horizontal E/vertical H.) He further suggested that high E/H ratio is due to electric dipoles and low E/H ratio is due to magnetic dipoles. As shown in this study of the dipole fields, similar results are also obtained for our apparent resistivity curves. However, we can further dif-

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ferentiate the vertical or horizontal electric dipoles because ρ_a is large for the horizontal dipole at short T, and small at long T, and vice versa for the vertical dipole. In any case, a single dipole is an oversimplified source, but so is a huge source that emits uniform plane waves as assumed by Cagniard. More observations of micropulsations, preferably fixed in space upon a known geological structure, and more rigorous study of their properties are required to further understand these long period electromagnetic variations.

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APPENDICES

APPENDIX I

1. Electric Hertz vector in a charge free medium whose ϵ and σ are not negligible

M.K.S. and $e^{-i\omega t}$ are used.

Maxwell's equations:

$$\nabla \times \vec{E} = -\dot{\vec{B}} \quad \text{(I-1)} \qquad \nabla \times \vec{H} = (\epsilon + \frac{i\sigma}{\omega})\dot{\vec{E}} \quad \text{(I-3)}$$

$$\nabla \cdot \vec{D} = 0 \quad \text{(I-2)} \qquad \nabla \cdot \vec{B} = 0 \quad \text{(I-4)}$$

By (I-4), $\vec{B} = \nabla \times \vec{A}$ (I-5)

$\vec{A}$ being an arbitrary vector, known as the electric vector potential.

By (I-5) and (I-1)

$$\nabla \times (\vec{E} + \dot{\vec{A}}) = 0 \quad \text{(I-6)}$$

Let $\vec{E} + \dot{\vec{A}} = -\nabla\Phi$

or $\vec{E} = -\nabla\phi - \dot{\vec{A}}$ (I-7)

ϕ being an arbitrary scalar function, or the scalar potential.

We now introduce the electric Hertz vector $\vec{\Pi}_e$ such that

$$\vec{A} = \mu(\epsilon + \frac{i\sigma}{\omega})\,\dot{\vec{\Pi}}_e \quad \text{(I-8)}$$

by (I-5)

$$\vec{H} = (\epsilon + \frac{i\sigma}{\omega})\nabla \times \dot{\vec{\Pi}}_e \quad \text{(I-9)}$$

By (I-7, I-8)

$$\vec{E} = -\nabla\phi - \mu(\epsilon + \frac{i\sigma}{\omega})\ \ddot{\vec{\Pi}}_e$$

Now define ϕ by

$$\phi = -\ \mathrm{div}\ \vec{\Pi}_e$$

then $$\vec{E} = \mathrm{grad\ div}\ \vec{\Pi}_e - \mu(\epsilon + \frac{i\sigma}{\omega})\ \ddot{\vec{\Pi}}_e \tag{I-10}$$

Substituting (I-9) and (I-10) into (I-3)

$$\nabla \times \nabla \times \dot{\vec{\Pi}}_e = \left\{ \mathrm{grad\ div}\ \dot{\vec{\Pi}}_e - \mu(\epsilon + \frac{i\sigma}{\omega})\ \dddot{\vec{\Pi}}_e \right\}$$

or $$(\nabla \cdot \nabla)\ \vec{\Pi}_e + (\omega^2\mu\epsilon + i\mu\sigma\omega)\ \vec{\Pi}_e = 0 \tag{I-11}$$

Define the complex permitivity

$$\bar{\epsilon} = (\epsilon + \frac{i\sigma}{\omega})$$

and $$k^2 = \omega^2\mu\bar{\epsilon}$$

then

$$\nabla^2\ \vec{\Pi}_e + k^2\ \vec{\Pi}_e = 0 \tag{I-12}$$

$$\vec{H} = -\ i\omega\bar{\epsilon}\nabla \times \vec{\Pi}_e \tag{I-13}$$

$$\vec{E} = k^2\ \vec{\Pi}_e + \mathrm{grad\ div}\ \vec{\Pi}_e \tag{I-14}$$

2. Magnetic Hertz vector in a charge free medium whose ϵ and σ are not negligible.

By (I-2)

$$\vec{D} = -\ \nabla \times \vec{A}' \tag{I-15}$$

$\vec{A}'$ being an arbitrary magnetic vector potential.

By (I-15) and (I-3)

$$\nabla \times \vec{H} = -\left(1 + \frac{i\sigma}{\epsilon\omega}\right)\nabla \times \dot{\vec{A}}'$$

or

$$\nabla \times \left\{ \vec{H} + \left(1 + \frac{i\sigma}{\epsilon\omega}\right)\dot{\vec{A}}' \right\} = 0 \qquad \text{(I-16)}$$

Let

$$\vec{H} + \left(1 + \frac{i\sigma}{\epsilon\omega}\right)\dot{\vec{A}}' = -\nabla\phi'$$

$$\therefore \qquad \vec{H} = -\nabla\phi' - \left(1 + \frac{i\sigma}{\epsilon\omega}\right)\dot{\vec{A}}' \qquad \text{(I-17)}$$

ϕ' being an arbitrary magnetic scalar potential.

We now introduce the magnetic Hertz vector $\vec{\Pi}_m$ such that

$$\vec{A}' = Q\,\dot{\vec{\Pi}}_m \qquad \text{(I-18)}$$

Q being a constant to be determined later.

Putting (I-18) into (I-15) and (I-17)

$$\vec{D} = -Q\nabla \times \dot{\vec{\Pi}}_m = i\omega Q\nabla \times \vec{\Pi}_m$$

$$\vec{E} = \frac{i\omega Q}{\epsilon}\nabla \times \vec{\Pi}_m \qquad \text{(I-19)}$$

$$\vec{H} = -\nabla\phi' - Q\left(1 + \frac{i\sigma}{\epsilon\omega}\right)\ddot{\vec{\Pi}}_m \qquad \text{(I-20)}$$

Now define ϕ' as

$$\phi' = -\operatorname{div}\vec{\Pi}_m$$

$$\therefore \qquad \vec{H} = \operatorname{grad}\operatorname{div}\vec{\Pi}_m + \omega^2 Q\left(1 + \frac{i\sigma}{\epsilon\omega}\right)\vec{\Pi}_m \qquad \text{(I-21)}$$

Putting (I-19) and (I-20) into (I-1), we have

$$\frac{i\omega Q}{\epsilon}\nabla \times \nabla \times \vec{\Pi}_m = +i\mu\omega\left\{\operatorname{grad}\operatorname{div}\vec{\Pi}_m + \omega^2 Q\left(1 + \frac{i\sigma}{\epsilon\omega}\right)\Pi_m\right\}$$

To be in conformity with (I-12), we define Q as follows:

$$Q = \mu\epsilon$$

$$\therefore \nabla^2\vec{\Pi}_m + k^2\vec{\Pi}_m = 0 \qquad \text{(I-22)}$$

and

$$\vec{E} = i\omega\mu\nabla \times \vec{\Pi}_m \qquad \text{(I-23)}$$

$$\vec{H} = k^2\vec{\Pi}_m + \text{grad div } \vec{\Pi}_m \qquad \text{(I-24)}$$

Summary:

$$\nabla^2\vec{\Pi}_e + k^2\vec{\Pi}_e = 0 \qquad \nabla^2\vec{\Pi}_m + k^2\vec{\Pi}_m = 0$$

$$H = - i\omega\bar{\epsilon}\nabla \times \vec{\Pi}_e \qquad \vec{E} = i\omega\mu\nabla \times \vec{\Pi}_m$$

$$\vec{E} = k^2\vec{\Pi}_e + \text{grad div } \vec{\Pi}_e \qquad \vec{H} = k^2\vec{\Pi}_m + \text{grad div } \vec{\Pi}_m$$

APPENDIX II

At $r = 0$ (or $\rho = 0$), the E.M. fields for the horizontal dipoles cannot be computed directly from the field equations summarized in Chapter II. In this appendix the field equations are modified for $r = 0$.

$$N(\mu,1) = \int_0^\infty \lambda^\mu J_1(\lambda\rho) e^{-\lambda h}\, d\lambda$$

$$T(\mu,1) = \int_0^\infty \lambda^\mu \chi(\lambda) J_1(\lambda\rho) e^{-\lambda h}\, d\lambda$$

using series representation for $J_1(\lambda\rho)$, the integrals become

$$N(\mu,1) = \sum_{\ell=0}^{\infty} \frac{(-1)^\ell}{\ell!(\ell+1)!} \int_0^\infty \lambda^\mu \left(\frac{\lambda\rho}{2}\right)^{2\ell+1} e^{-\lambda h}\, d\lambda \qquad \text{(II-1)}$$

$$T(\mu,1) = \sum_{\ell=0}^{\infty} \frac{(-1)^\ell}{\ell!(\ell+1)!} \int_0^\infty \lambda^\mu \chi(\lambda) \left(\frac{\lambda\rho}{2}\right)^{2\ell+1} e^{-\lambda h}\, d\lambda \qquad \text{(II-2)}$$

$$\frac{1}{\rho} N(\mu,1) = \sum_{\ell=0}^{\infty} \frac{(-1)^\ell}{\ell!(\ell+1)!} \int_0^\infty \frac{\lambda^{\mu+1}}{2} \left(\frac{\lambda\rho}{2}\right)^{2\ell} e^{-\lambda h}\, d\lambda$$

$$= \frac{1}{2} \int_0^\infty \lambda^{\mu+1} e^{-\lambda h}\, d\lambda + \sum_{\ell=1}^{\infty} \frac{(-1)^\ell}{2\cdot\ell!(\ell+1)!} \int_0^\infty \lambda^{\mu+1} \left(\frac{\lambda\rho}{2}\right)^{2\ell} e^{-\lambda h}\, d\lambda$$

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$$\frac{1}{\rho} N(\mu,1)\Big|_{\rho=0} = \frac{1}{2}\int_0^\infty \lambda^{\mu+1} e^{-\lambda h} d\lambda + 0$$

$$= \frac{1}{2}\int_0^\infty \lambda^{\mu+1} J_0(\lambda\rho)e^{-\lambda h} d\lambda \Big|_{\rho=0}$$

Since $J_0(\lambda\rho)\Big|_{\rho=0} = 1$.

$$\therefore \frac{1}{\rho} N(\mu,1)\Big|_{\rho=0} = \frac{1}{2} N(\mu+1,0)\Big|_{\rho=0} \qquad \text{(II-3)}$$

Similarly

$$\frac{1}{\rho} T(\mu,1)\Big|_{\rho=0} = \frac{1}{2} T(\mu+1,0)\Big|_{\rho=0} \qquad \text{(II-4)}$$

(II-3, II-4) hold for all μ.

Substituting (II-3, II-4) into the field equations in Chapter II, and using

$$\cos\varphi = \lim_{\rho\to 0} \frac{x}{\rho} = 1, \ \sin\varphi = \lim_{\rho\to 0} \frac{y}{\rho} = 1 ,$$

we have the following field expressions:

H.M.D. $\quad r = 0$

$$E_x = H_y = E_z = H_z = 0$$

$$E_y = i\omega\mu_0 \cdot \frac{1}{2}\left\{N(1,0) + T(1,0)\right\} \qquad \text{(II-5)}$$

$$H_x = \frac{1}{2}\left\{T(2,0) - N(2,0)\right\} \qquad \text{(II-6)}$$

H.E.D. $\quad r = 0$

$$H_x = E_y = H_z = E_z = 0$$

$$E_x = k_0^2 \left\{ \frac{3}{4} N(0,0) + T(0,0) \right\} \tag{II-7}$$

$$H_y = i\omega\epsilon_0 \left\{ \frac{1}{2} T(1,0) - \frac{3}{2} N(1,0) \right\} \tag{II-8}$$

APPENDIX III

In free space a magnetic dipole of dipole moment 4π amp-m^2 at (0,0,h) has a magnetic Hertz vector

$$\vec{\Pi}_m = \hat{i}\,\Pi_x\,, \qquad \Pi_y = \Pi_z = 0$$

where

$$\Pi_x = \frac{e^{ik_0R}}{R}\,, \qquad R^2 = x^2 + y^2 + [z - h]^2$$

$$\therefore \qquad \operatorname{div} \vec{\Pi}_m = \frac{\partial}{\partial x}\Pi_x = e^{ik_0R}\,\frac{x}{R^2}\left(ik_0 - \frac{1}{R}\right)$$

$$H_x = k_0^2\,\Pi_x + \frac{\partial}{\partial x}\operatorname{div}\vec{\Pi}_m$$

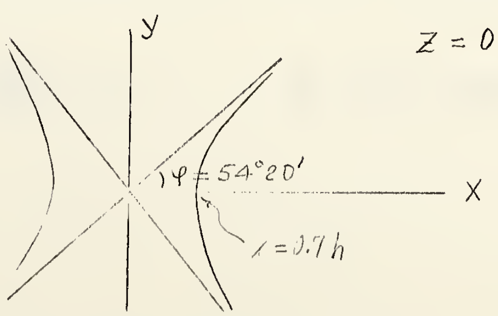
$$\sim e^{ik_0R}\,\frac{3r^2\cos^2\varphi - r^2 - 1}{h^3(1 + r^2)^{5/2}} \qquad \text{at } z = 0 \qquad \text{(III-1)}$$

where $r = \rho/h$, $\rho^2 = x^2 + y^2$, $\cos\varphi = x/\rho$

$H_x = 0$ on the plane $z = 0$ when

$$3r^2\cos^2\varphi - r^2 - 1 = 0 \qquad \text{(III-2)}$$

(III-2) describes a hyperbola as in the following diagram.



On these two arms of the hyperbola $H_x = 0$.

APPENDIX IV

$$G_0(\lambda) = \beta_0(\lambda)$$

$$= \frac{\lambda}{p_0}\left\{\frac{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d} - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_0+p_0\epsilon_1)(p_1\epsilon_2+p_2\epsilon_1) - (p_1\epsilon_0-p_0\epsilon_1)(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d}}\right\}$$

$$\frac{\lambda}{p_0} - G_0(\lambda) \simeq -\frac{2p_1\epsilon_0}{\lambda\epsilon_1}\;\frac{(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d} - (p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_2+p_2\epsilon_1) + (p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d}}$$

$$= -\,2f(\epsilon_0,\lambda)$$

In the significant range of λ

$$\left|\frac{(p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d} - (p_1\epsilon_2+p_2\epsilon_1)}{(p_1\epsilon_2+p_2\epsilon_1) + (p_1\epsilon_2-p_2\epsilon_1)e^{-2p_1d}}\right| \sim 1$$

$$\lambda \sim p_1$$

$$f(\epsilon_0,\lambda) \sim \frac{\epsilon_0}{\epsilon_1} \sim \frac{\epsilon_0\omega}{i\sigma_1} << 1 \qquad \text{if } T \geqslant .1 \text{ sec.}$$

APPENDIX V

$N(\mu,\nu)$, $z = 0$

$$Q = (\rho^2 + h^2) = h^2(1 + r^2) , \qquad r = \rho/h$$

$$N(0,0) = \frac{1}{Q^{1/2}} \qquad N(0,1) = \frac{1}{\rho}\left(1 - \frac{h}{Q^{1/2}}\right)$$

$$N(1,0) = \frac{h}{Q^{3/2}} \qquad N(1,1) = \frac{\rho}{Q^{3/2}}$$

$$N(2,0) = \left\{- \frac{1}{Q^{3/2}} + \frac{3h^2}{Q^{5/2}}\right\} \qquad N(2,1) = \frac{3h\rho}{Q^{5/2}}$$

$$N(3,0) = 3\left\{- \frac{3h}{Q^{5/2}} + \frac{5h^3}{Q^{7/2}}\right\} \qquad N(3,1) = 3\rho\left\{- \frac{1}{Q^{5/2}} + \frac{5h^2}{Q^{7/2}}\right\}$$

$$N(4,0) = 3\left\{\frac{3}{Q^{5/2}} - \frac{30h^2}{Q^{7/2}} + \frac{35h^4}{Q^{9/2}}\right\} \qquad N(4,1) = - 15\rho\left\{\frac{3h}{Q^{7/2}} - \frac{7h^3}{Q^{9/2}}\right\}$$

$$N(\mu+1,0) = (-) \frac{\partial}{\partial h} N(\mu,0) \qquad N(\mu+1,1) = - \frac{\partial}{\partial \rho} N(\mu,0)$$

APPENDIX VI

Differentiations of $\chi(\lambda)$ can be greatly simplified by writing

$$\chi(\lambda) = 2\lambda\Gamma(\lambda) - 1$$

$$\Gamma(\lambda) = \frac{(p_1+p_2) + (p_1-p_2)e^{-2p_1 d}}{(p_1+\lambda)(p_1+p_2) - (p_1-\lambda)(p_1-p_2)e^{-2p_1 d}}$$

$$\chi'(\lambda) = 2\left\{\Gamma(\lambda) + \lambda\Gamma'(\lambda)\right\}$$

$$\chi''(\lambda) = 2\left\{2\Gamma'(\lambda) + \lambda\Gamma''(\lambda)\right\}$$

$$\chi'''(\lambda) = 2\left\{3\Gamma''(\lambda) + \lambda\Gamma'''(\lambda)\right\}$$

$$\therefore \quad \chi(0) = -1$$

$$\chi'(0) = 2\Gamma(0)$$

$$\chi''(0) = 4\Gamma'(0)$$

$$\chi'''(0) = 6\Gamma''(0)$$

$$\Gamma(0) = -\frac{i}{k_1} L$$

$$\Gamma'(0) = \frac{L^2}{k_1^2}$$

$$\Gamma''(0) = i\,\frac{n^2}{k_1^3}\left\{ 1 - nL - L^2 + 2nL^3 \right\} - \frac{2(1 - n)de^{\theta}}{k_1^2\left\{(1 + n) - (1 + n)e^{\theta}\right\}}$$

$$L = \frac{(1 + n) + (1 - n)e^{\theta}}{(1 + n) - (1 - n)e^{\theta}} \quad , \quad n = \frac{k_2}{k_1} \quad , \quad \theta = - i2k_1 d$$

$$k_j^2 = \omega^2\mu_0(\epsilon_j + \frac{i\sigma_j}{\omega})$$

APPENDIX VII

Separation into real and imaginary parts of the functions $\chi(\lambda)$ and $f(\lambda)$ as given on page 64.

(1) $\chi(\lambda)$: $$\chi(\lambda) = \text{Re}\,\chi(\lambda) + i\,\text{Im}\,\chi(\lambda)$$

$$\text{Re}\,\chi(\lambda) = \frac{R(u)R(v) + Im(u)Im(v)}{[R(v)]^2 + [Im(v)]^2} \qquad \text{Im}\,\chi(\lambda) = \frac{Im(u)R(v) - R(u)Im(v)}{[R(v)]^2 + [Im(v)]^2}$$

$$R(u) = R(\zeta_2)R(\xi) - Im(\zeta_2)Im(\xi) - R(\zeta_3)$$

$$Im(u) = R(\zeta_2)Im(\xi) + Im(\zeta_2)R(\xi) - Im(\zeta_3)$$

$$R(v) = R(\zeta_1) - R(\zeta_4)R(\xi) + Im(\zeta_4)Im(\xi)$$

$$Im(v) = Im(\zeta_1) - R(\zeta_4)Im(\xi) - Im(\zeta_4)R(\xi)$$

$$R(\xi) = e^{-2A_1 d\cos\theta_1} \cos(2A_1 d\sin\theta_1)$$

$$Im(\xi) = e^{-2A_1 d\cos\theta_1} \sin(2A_1 d\sin\theta_1)$$

$$R(\zeta_1) = (A_1\cos\theta_1 + \lambda)(A_1\cos\theta_1 + A_2\cos\theta_2)$$

$$- A_1\sin\theta_1(A_1\sin\theta_1 + A_2\sin\theta_2)$$

$$Im(\zeta_1) = -(A_1\cos\theta_1 + \lambda)(A_1\sin\theta_1 + A_2\sin\theta_2)$$
$$- (A_1\sin\theta_1)(A_1\cos\theta_1 + A_2\cos\theta_2)$$

$$R(\zeta_2) = (A_1\cos\theta_1 + \lambda)(A_1\cos\theta_1 - A_2\cos\theta_2)$$
$$- A_1\sin\theta_1(A_1\sin\theta_1 - A_2\sin\theta_2)$$

$$Im(\zeta_2) = -(A_1\cos\theta_1 + \lambda)(A_1\sin\theta_1 - A_2\sin\theta_2)$$
$$- A_1\sin\theta_1(A_1\cos\theta_1 - A_2\cos\theta_2)$$

$$R(\zeta_3) = (A_1\cos\theta_1 - \lambda)(A_1\cos_1\theta_1 + A_2\cos\theta_2)$$
$$- A_1\sin\theta_1(A_1\sin\theta_1 + A_2\sin\theta_2)$$

$$Im(\zeta_3) = -(A_1\cos\theta_1 - \lambda)(A_1\sin\theta_1 + A_2\sin\theta_2)$$
$$- A_1\sin\theta_1(A_1\cos\theta_1 + A_2\cos\theta_2)$$

$$R(\zeta_4) = (A_1\cos\theta_1 - \lambda)(A_1\cos_1\theta_1 - A_2\cos\theta_2)$$
$$- A_1\sin\theta_1(A_1\sin\theta_1 - A_2\sin\theta_2)$$

$$Im(\zeta_4) = -(A_1\cos\theta_1 - \lambda)(A_1\sin\theta_1 - A_2\sin\theta_2)$$
$$- A_1\sin\theta_1(A_1\cos\theta_1 - A_2\cos\theta_2)$$

$$A_1 = \left\{\lambda^4 + [\omega\sigma_1\mu_0]^2\right\}^{1/4} \qquad A_2 = \left\{\lambda^4 + [\omega\sigma_2\mu_0]^2\right\}^{1/4}$$

$$\theta_1 = \frac{1}{2}\arctan\left(\frac{\omega\sigma_1\mu_0}{\lambda^2}\right) \qquad \theta_2 = \frac{1}{2}\arctan\left(\frac{\omega\sigma_2\mu_0}{\lambda^2}\right)$$

(2) $f(\lambda)$: $$f(\lambda) = \mathrm{Re}\, f(\lambda) + i\, \mathrm{Im}\, f(\lambda)$$

$$\mathrm{Re} f(\lambda) = - \frac{A_1 \omega \epsilon_0}{\sigma_1 \lambda} \left[\sin\theta_1 \times \mathrm{Re}(\Sigma) - \cos\theta_1 \times \mathrm{Im}(\Sigma) \right]$$

$$\mathrm{Im} f(\lambda) = - \frac{A_1 \omega \epsilon_0}{\sigma_1 \lambda} \left[\sin\theta_1 \times \mathrm{Im}(\Sigma) + \cos\theta_1 \times \mathrm{Re}(\Sigma) \right]$$

$$\mathrm{Re}(\Sigma) = \frac{\mathrm{Re}(\Gamma_1)\mathrm{Re}(\Gamma_2) + \mathrm{Im}(\Gamma_1)\mathrm{Im}(\Gamma_2)}{[\mathrm{Re}(\Gamma_2)]^2 + [\mathrm{Im}(\Gamma_2)]^2}$$

$$\mathrm{Im}(\Sigma) = \frac{\mathrm{Im}(\Gamma_1)\mathrm{Re}(\Gamma_2) - \mathrm{Re}(\Gamma_1)\mathrm{Im}(\Gamma_2)}{[\mathrm{Re}(\Gamma_2)]^2 + [\mathrm{Im}(\Gamma_2)]^2}$$

$$\mathrm{Re}(\Gamma_1) = [\mathrm{Re}(\varphi) - \mathrm{Re}(\zeta_1)] \qquad \mathrm{Im}(\Gamma_1) = [\mathrm{Im}(\varphi_1) - \mathrm{Im}(\zeta_1)]$$

$$\mathrm{Re}(\Gamma_2) = [\mathrm{Re}(\varphi) + \mathrm{Re}(\zeta_1)] \qquad \mathrm{Im}(\Gamma_2) = [\mathrm{Im}(\varphi) + \mathrm{Im}(\zeta_1)]$$

$$\mathrm{Re}(\varphi) = [\mathrm{Re}(\xi)\mathrm{Re}(\zeta_2) - \mathrm{Im}(\xi)\mathrm{Im}(\zeta_2)]$$

$$\mathrm{Im}(\varphi) = [\mathrm{Re}(\xi)\mathrm{Im}(\zeta_2) + \mathrm{Im}(\xi)\mathrm{Re}(\zeta_2)]$$

$$\mathrm{Re}(\zeta_1) = (nA_1\cos\theta_1 + A_2\cos\theta_2)$$

$$\mathrm{Im}(\zeta_1) = -(nA_1\sin\theta_1 + A_2\sin\theta_2)$$

$$\mathrm{Re}(\zeta_2) = (nA_1\cos\theta_1 - A_2\cos\theta_2)$$

$$\mathrm{Im}(\zeta_2) = (A_2 \sin\theta_2 - nA_1 \sin\theta_1)$$

$$\mathrm{Re}(\xi) = e^{-2A_1 d\cos\theta_1} \cos[2A_1 d\sin\theta_1]$$

$$\mathrm{Im}(\xi) = e^{-2A_1 d\cos\theta_1} \sin[2A_1 d\sin\theta_1]$$

$$A_1 = \left\{\lambda^4 + [\omega\sigma_1\mu_0]^2\right\}^{1/4} \qquad A_2 = \left\{\lambda^4 + [\omega\sigma_2\mu_0]^2\right\}^{1/4}$$

$$\theta_1 = \frac{1}{2}\arctan\left(\frac{\omega\sigma_1\mu_0}{\lambda^2}\right) \qquad \theta_2 = \frac{1}{2}\arctan\left(\frac{\omega\sigma_2\mu_0}{\lambda^2}\right)$$

$$n = \frac{\sigma_2}{\sigma_1}$$

APPENDIX VIII

	a_j	z_j
1	0.0271524594	0.9894009350
2	0.0622535239	0.9445740231
3	0.0951585117	0.8656312024
4	0.1246289713	0.7554044084
5	0.1495959888	0.6178762444
6	0.1691565194	0.4580167777
7	0.1826034150	0.2816035508
8	0.1894506105	0.0950125098
9	0.1894506105	0.0950125098
10	0.1826034150	0.2816035508
11	0.1691565194	0.4580167777
12	0.1495959888	0.6178762444
13	0.1246289713	0.7554044084
14	0.0951585117	0.8656312024
15	0.0622535239	0.9445750231
16	0.0271524594	0.9894009350

This table is taken from Lowan <u>et al</u> (1942)

APPENDIX IX

Numerical values of the integrals $T(\mu,\nu)$ and $\tau(2,1)$.

$R = \rho/h$

$S1 = \sigma_1 \ (\text{ohm-m})^{-1}$

$S2 = \sigma_2 \ (\text{ohm-n})^{-1}$

D = thickness of top layer (m)

E = elevation of the dipole (m)

(J-1) denotes the number of terms used in computing the integral for $J < 20$. For $J = 20$, J denotes the number of terms used.

T(0,0)
R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.99644175E-05	.35330172E-07	2
.20	-.99496800E-05	.49817063E-07	2
.50	-.99204435E-05	.78299215E-07	2
1.00	-.98875010E-05	.11022012E-06	2
2.00	-.98388955E-05	.15297629E-06	2
5.00	-.97647620E-05	.22395993E-06	2
10.00	-.97204830E-05	.34225783E-06	2
20.00	-.96500710E-05	.60049545E-06	2
50.00	-.93329770E-05	.12953641E-05	2
100.00	-.86501765E-05	.20824814E-05	2
200.00	-.73971430E-05	.28212042E-05	2
500.00	-.51486490E-05	.31687520E-05	2
1000.00	-.35445426E-05	.27665456E-05	2
2000.00	-.24671338E-05	.22245825E-05	2
5000.00	-.13339375E-05	.17469097E-05	2
10000.00	-.59755870E-06	.12816129E-05	2

T(1,0)
R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.99288360E-10	.70408715E-12	2
.20	-.98993635E-10	.99131790E-12	2
.50	-.98409020E-10	.15534800E-11	2
1.00	-.97750375E-10	.21794541E-11	2
2.00	-.96780440E-10	.30095754E-11	2
5.00	-.95301695E-10	.43797139E-11	2
10.00	-.94340520E-10	.66856610E-11	2
20.00	-.92554205E-10	.11616685E-10	2
50.00	-.84589270E-10	.23433670E-10	2
100.00	-.70015530E-10	.33262649E-10	2
200.00	-.49100222E-10	.37241773E-10	2
500.00	-.23448138E-10	.30595254E-10	2
1000.00	-.10960418E-10	.21177715E-10	2
2000.00	-.50443475E-11	.12738286E-10	2
5000.00	-.20209706E-11	.63428380E-11	2
10000.00	-.84244460E-12	.37035010E-11	2

T(2,0)
R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.19786508E-14	.21047211E-16	2
.20	-.19698099E-14	.29589157E-16	2
.50	-.19522759E-14	.46230724E-16	2
1.00	-.19325256E-14	.64639369E-16	2
2.00	-.19035035E-14	.88800315E-16	2
5.00	-.18592618E-14	.12850045E-15	2
10.00	-.18279477E-14	.19579786E-15	2
20.00	-.17633244E-14	.33495427E-15	2
50.00	-.14940671E-14	.62118505E-15	2
100.00	-.10847166E-14	.77326635E-15	2
200.00	-.62276510E-15	.72838315E-15	2
500.00	-.21350247E-15	.46707445E-15	2
1000.00	-.76250885E-16	.27875003E-15	2
2000.00	-.24040198E-16	.15050679E-15	2
5000.00	-.55114675E-17	.62967725E-16	2
10000.00	-.18122252E-17	.32251456E-16	2

T(0,0)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.97722543E-05	.33325374E-07	4
.20	-.97583576E-05	.46998190E-07	4
.50	-.97307931E-05	.73893652E-07	4
1.00	-.96997300E-05	.10405819E-06	4
2.00	-.96538892E-05	.14450700E-06	4
5.00	-.95839700E-05	.21169830E-06	4
10.00	-.95426484E-05	.32356804E-06	4
20.00	-.94783044E-05	.56845507E-06	4
50.00	-.91867807E-05	.12354574E-05	4
100.00	-.85437801E-05	.20074112E-05	4
200.00	-.73335715E-05	.27517659E-05	4
500.00	-.51452275E-05	.31030096E-05	4
1000.00	-.35649852E-05	.28136085E-05	4
2000.00	-.23042588E-05	.22395920E-05	4
5000.00	-.13373498E-05	.14414060E-05	4
10000.00	-.89890270E-06	.10834528E-05	3

T(1,0)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.93654307E-10	.62608129E-12	4
.20	-.93392443E-10	.88179434E-12	4
.50	-.92872998E-10	.13827981E-11	4
1.00	-.92287723E-10	.19415078E-11	4
2.00	-.91425420E-10	.26841542E-11	4
5.00	-.90110800E-10	.39109966E-11	4
10.00	-.89274335E-10	.59731749E-11	4
20.00	-.87761231E-10	.10419143E-10	4
50.00	-.80846445E-10	.21389872E-10	4
100.00	-.67625678E-10	.30995759E-10	4
200.00	-.47952627E-10	.35414528E-10	4
500.00	-.23080786E-10	.29399131E-10	4
1000.00	-.11257475E-10	.20685028E-10	4
2000.00	-.48954032E-11	.12978534E-10	4
5000.00	-.15428111E-11	.60884506E-11	4
10000.00	-.75301222E-12	.33315382E-11	4

T(2,0)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.17594458E-14	.17271179E-16	4
.20	-.17522009E-14	.24294979E-16	4
.50	-.17378308E-14	.38003712E-16	4
1.00	-.17216431E-14	.53207651E-16	4
2.00	-.16978322E-14	.73243880E-16	4
5.00	-.16615456E-14	.10620490E-15	4
10.00	-.16367413E-14	.16204862E-15	4
20.00	-.15868862E-14	.27960313E-15	4
50.00	-.13686724E-14	.53537890E-15	4
100.00	-.10140768E-14	.68845441E-15	4
200.00	-.59375288E-15	.66649323E-15	4
500.00	-.20558252E-15	.43658985E-15	4
1000.00	-.75477595E-16	.26131023E-15	4
2000.00	-.24830435E-16	.14331561E-15	4
5000.00	-.49675726E-17	.60232757E-16	4
10000.00	-.15025069E-17	.30523883E-16	4

T(0,1)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.96425610E-06	.66413440E-08	4
.20	-.96147715E-06	.93522624E-08	4
.50	-.95596512E-06	.14660782E-07	4
1.00	-.94975470E-06	.20576260E-07	4
2.00	-.94060657E-06	.28430012E-07	4
5.00	-.92665982E-06	.41398464E-07	4
10.00	-.91768925E-06	.63211341E-07	4
20.00	-.90123272E-06	.11004742E-06	3
50.00	-.82695462E-06	.22393208E-06	3
100.00	-.68812072E-06	.32112255E-06	3
200.00	-.48513457E-06	.36333782E-06	3
500.00	-.23335132E-06	.29918185E-06	3
1000.00	-.11120835E-06	.21093412E-06	3
2000.00	-.48127420E-07	.12822627E-06	3
5000.00	-.18449430E-07	.61208072E-07	3
10000.00	-.87511772E-08	.35411012E-07	3

T(1,1)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.18663769E-10	.19094580E-12	4
.20	-.18583614E-10	.26851745E-12	4
.50	-.18424639E-10	.41977682E-12	4
1.00	-.18245561E-10	.58730949E-12	4
2.00	-.17982289E-10	.80762818E-12	4
5.00	-.17581015E-10	.11698488E-11	4
10.00	-.17301701E-10	.17837444E-11	4
20.00	-.16732222E-10	.30643410E-11	4
50.00	-.14302716E-10	.57721541E-11	4
100.00	-.10489104E-10	.72995862E-11	3
200.00	-.60823472E-11	.69705562E-11	3
500.00	-.20925129E-11	.45091805E-11	3
1000.00	-.76537475E-12	.27016472E-11	3
2000.00	-.24159681E-12	.14719139E-11	3
5000.00	-.51554720E-13	.61421140E-12	3
10000.00	-.17171194E-13	.31320722E-12	3

T(2,1)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.53659168E-15	.72471521E-17	4
.20	-.53353998E-15	.10177520E-16	4
.50	-.52748837E-15	.15867637E-16	4
1.00	-.52067300E-15	.22131818E-16	4
2.00	-.51067417E-15	.30290959E-16	4
5.00	-.49543107E-15	.43661379E-16	4
10.00	-.48398410E-15	.66418318E-16	4
20.00	-.45901728E-15	.11206009E-15	4
50.00	-.36118277E-15	.19357867E-15	4
100.00	-.23270419E-15	.21676833E-15	4
200.00	-.11316979E-15	.17932948E-15	4
500.00	-.30056122E-16	.98242985E-16	4
1000.00	-.91848540E-17	.53749339E-16	4
2000.00	-.25364105E-17	.27828650E-16	4
5000.00	-.43097300E-18	.11275332E-16	4
10000.00	-.11257796E-18	.56529726E-17	4

T(0,0)

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.31611526E-05	.11279660E-08	20
.20	-.31606867E-05	.15968261E-08	20
.50	-.31597624E-05	.25296819E-08	20
1.00	-.31587197E-05	.35929977E-08	20
2.00	-.31571761E-05	.50533817E-08	20
5.00	-.31548232E-05	.75339411E-08	20
10.00	-.31536842E-05	.11571869E-07	20
20.00	-.31528129E-05	.20471776E-07	20
50.00	-.31516234E-05	.47105017E-07	20
100.00	-.31552396E-05	.89797058E-07	19
200.00	-.31792706E-05	.19773902E-06	18
500.00	-.30767932E-05	.62108948E-06	16
1000.00	-.26345035E-05	.99827340E-06	15
2000.00	-.19838561E-05	.11394318E-05	15
5000.00	-.12070487E-05	.97857204E-06	14
10000.00	-.79910444E-06	.75916088E-06	14

T(1,0)

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.31701544E-11	-.78466765E-14	20
.20	-.31734171E-11	-.11079243E-13	20
.50	-.31798926E-11	-.17460940E-13	20
1.00	-.31871866E-11	-.24654250E-13	20
2.00	-.31979668E-11	-.34375484E-13	20
5.00	-.32144386E-11	-.50583453E-13	20
10.00	-.32234804E-11	-.77224706E-13	20
20.00	-.32345042E-11	-.13590806E-12	20
50.00	-.32740919E-11	-.31518710E-12	20
100.00	-.34125984E-11	-.63399205E-12	20
200.00	-.41160594E-11	-.10242620E-11	20
500.00	-.54129657E-11	.28437153E-12	20
1000.00	-.45820085E-11	.19314468E-11	19
2000.00	-.28600703E-11	.24147429E-11	18
5000.00	-.11729067E-11	.17803058E-11	18
10000.00	-.54403724E-12	.11599309E-11	17

T(2,0)

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	.22051560E-16	-.84434675E-19	20
.20	.22016603E-16	-.11943250E-18	20
.50	.21947217E-16	-.18889501E-18	20
1.00	.21869070E-16	-.26778590E-18	20
2.00	.21753361E-16	-.37560499E-18	20
5.00	.21576676E-16	-.55750119E-18	20
10.00	.21487620E-16	-.85363732E-18	20
20.00	.21408214E-16	-.15012673E-17	20
50.00	.21353261E-16	-.34613961E-17	20
100.00	.21426352E-16	-.76219350E-17	20
200.00	.15889079E-16	-.17092902E-16	20
500.00	-.52220677E-17	-.15555217E-16	20
1000.00	-.96081510E-17	-.38133709E-17	20
2000.00	-.60542829E-17	.20451163E-17	20
5000.00	-.19715858E-17	.25454967E-17	20
10000.00	-.71423302E-18	.16613346E-17	20

T(0,1)
R = .30E+01   S1= .2000E-00 S2= .2000E-02   D= .40E+04   E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.22758650E-05	.33720763E-08	20
.20	-.22744663E-05	.47667202E-08	20
.50	-.22716927E-05	.75294773E-08	20
1.00	-.22685662E-05	.10658913E-07	20
2.00	-.22639413E-05	.14918860E-07	20
5.00	-.22568836E-05	.22082993E-07	20
10.00	-.22532067E-05	.33814453E-07	20
20.00	-.22493526E-05	.59687660E-07	20
50.00	-.22372327E-05	.13724510E-06	19
100.00	-.22107125E-05	.26216907E-06	18
200.00	-.21146042E-05	.50228816E-06	17
500.00	-.16210656E-05	.89895740E-06	15
1000.00	-.10306051E-05	.94786775E-06	15
2000.00	-.54480596E-06	.76080282E-06	14
5000.00	-.19872843E-06	.44146968E-06	14
10000.00	-.87839288E-07	.26307032E-06	14

T(1,1)
R = .30E+01   S1= .2000E-00 S2= .2000E-02   D= .40E+04   E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.94767067E-11	.10145001E-13	20
.20	-.94725114E-11	.14357724E-13	20
.50	-.94641893E-11	.22732168E-13	20
1.00	-.94548108E-11	.32264511E-13	20
2.00	-.94409211E-11	.45334660E-13	20
5.00	-.94197335E-11	.67480662E-13	20
10.00	-.94093258E-11	.10352746E-12	20
20.00	-.94008446E-11	.18279684E-12	20
50.00	-.93908385E-11	.41804337E-12	20
100.00	-.94381334E-11	.83099631E-12	20
200.00	-.94132267E-11	.20047553E-11	20
500.00	-.70366898E-11	.44524238E-11	18
1000.00	-.38861692E-11	.45414119E-11	18
2000.00	-.16616918E-11	.32990269E-11	17
5000.00	-.43008843E-12	.16536459E-11	17
10000.00	-.14177507E-12	.89223462E-12	17

T(2,1)
R = .30E+01   S1= .2000E-00 S2= .2000E-02   D= .40E+04   E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.28511115E-16	-.50221658E-19	20
.20	-.28532097E-16	-.70781772E-19	20
.50	-.28573710E-16	-.11114341E-18	20
1.00	-.28620591E-16	-.15627925E-18	20
2.00	-.28689818E-16	-.21653945E-18	20
5.00	-.28795660E-16	-.31561668E-18	20
10.00	-.28858495E-16	-.47981124E-18	20
20.00	-.28948960E-16	-.84266120E-18	20
50.00	-.29381279E-16	-.20451909E-17	20
100.00	-.31656992E-16	-.40478249E-17	20
200.00	-.39279708E-16	-.13511266E-17	20
500.00	-.34903088E-16	.17768060E-16	20
1000.00	-.18216112E-16	.21193152E-16	20
2000.00	-.68580269E-17	.15166675E-16	20
5000.00	-.14518300E-17	.71724933E-17	20
10000.00	-.40809571E-18	.37347085E-17	20

T(0,0)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.19608922E-05	.26918779E-09	20
.20	-.19607805E-05	.38118189E-09	20
.50	-.19605602E-05	.60420472E-09	20
1.00	-.19603116E-05	.85870816E-09	20
2.00	-.19599434E-05	.12088069E-08	20
5.00	-.19593826E-05	.18048666E-08	20
10.00	-.19591145E-05	.27753864E-08	20
20.00	-.19589222E-05	.49181101E-08	20
50.00	-.19586884E-05	.11424409E-07	20
100.00	-.19588332E-05	.21777178E-07	20
200.00	-.19640842E-05	.40069614E-07	20
500.00	-.20097297E-05	.14605293E-06	20
1000.00	-.19486519E-05	.39120960E-06	20
2000.00	-.16553802E-05	.63350451E-06	20
5000.00	-.11135595E-05	.70061988E-06	20
10000.00	-.76683233E-06	.60409747E-06	20

T(1,0)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.75657259E-12	-.23753901E-14	20
.20	-.75755691E-12	-.33573958E-14	20
.50	-.75951211E-12	-.53019568E-14	20
1.00	-.76171556E-12	-.75033831E-14	20
2.00	-.76497372E-12	-.10497711E-13	20
5.00	-.76994702E-12	-.15528871E-13	20
10.00	-.77255558E-12	-.23767004E-13	20
20.00	-.77533758E-12	-.41918080E-13	20
50.00	-.78434235E-12	-.95996116E-13	20
100.00	-.80095243E-12	-.18082086E-12	20
200.00	-.85176119E-12	-.37474062E-12	20
500.00	-.14757118E-11	-.67361017E-12	20
1000.00	-.20172356E-11	-.10417919E-12	20
2000.00	-.17484123E-11	.63164789E-12	20
5000.00	-.91213811E-12	.84635369E-12	20
10000.00	-.46746438E-12	.65979886E-12	20

T(2,0)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	.66756959E-17	-.92398646E-20	20
.20	.66718738E-17	-.13065752E-19	20
.50	.66642813E-17	-.20652605E-19	20
1.00	.66557229E-17	-.29258814E-19	20
2.00	.66430719E-17	-.41003530E-19	20
5.00	.66237500E-17	-.60900053E-19	20
10.00	.66136237E-17	-.93162464E-19	20
20.00	.66042786E-17	-.16269451E-18	20
50.00	.65885064E-17	-.36651433E-18	20
100.00	.66229103E-17	-.65683605E-18	20
200.00	.70897052E-17	-.15989267E-17	20
500.00	.44863519E-17	-.58125456E-17	20
1000.00	-.57789527E-18	-.48729947E-17	20
2000.00	-.20911910E-17	-.15949791E-17	20
5000.00	-.11164653E-17	.32083186E-18	20
10000.00	-.48031244E-18	.45827449E-18	20

T(0,1)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.16064254E-05	.13413909E-08	20
.20	-.16058695E-05	.18966924E-08	20
.50	-.16047670E-05	.29976158E-08	20
1.00	-.16035237E-05	.42461833E-08	20
2.00	-.16016847E-05	.59486103E-08	20
5.00	-.15988795E-05	.88175608E-08	20
10.00	-.15974367E-05	.13512150E-07	20
20.00	-.15959885E-05	.23870335E-07	20
50.00	-.15915958E-05	.54947547E-07	20
100.00	-.15825800E-05	.10369591E-06	20
200.00	-.15623113E-05	.19580216E-06	20
500.00	-.14316427E-05	.45690501E-06	20
1000.00	-.11034734E-05	.65701897E-06	20
2000.00	-.68160235E-06	.66191382E-06	20
5000.00	-.28353118E-06	.45809087E-06	20
10000.00	-.13297232E-06	.29481754E-06	20

T(1,1)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.37698461E-11	.15496241E-14	20
.20	-.37692054E-11	.21942103E-14	20
.50	-.37679356E-11	.34773979E-14	20
1.00	-.37665046E-11	.49412746E-14	20
2.00	-.37643841E-11	.69541852E-14	20
5.00	-.37611532E-11	.10378005E-13	20
10.00	-.37596080E-11	.15952693E-13	20
20.00	-.37584784E-11	.28260202E-13	20
50.00	-.37568688E-11	.65527462E-13	20
100.00	-.37580934E-11	.12207801E-12	20
200.00	-.38154345E-11	.23484794E-12	20
500.00	-.38546622E-11	.10396767E-11	20
1000.00	-.29153672E-11	.18761911E-11	20
2000.00	-.15723396E-11	.18821812E-11	20
5000.00	-.49155186E-12	.11591028E-11	20
10000.00	-.17717598E-12	.67297088E-12	20

T(2,1)

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	-.43552524E-17	-.12885695E-19	20
.20	-.43606059E-17	-.18194905E-19	20
.50	-.43712332E-17	-.28678625E-19	20
1.00	-.43832014E-17	-.40498985E-19	20
2.00	-.44008885E-17	-.56483604E-19	20
5.00	-.44279285E-17	-.83228622E-19	20
10.00	-.44429202E-17	-.12696343E-18	20
20.00	-.44606718E-17	-.22211580E-18	20
50.00	-.45162941E-17	-.50018003E-18	20
100.00	-.46027211E-17	-.96950058E-18	20
200.00	-.52614309E-17	-.21960712E-17	20
500.00	-.94675393E-17	-.98398872E-18	20
1000.00	-.84811477E-17	.36249968E-17	20
2000.00	-.43990162E-17	.48286122E-17	20
5000.00	-.11630371E-17	.29920078E-17	20
10000.00	-.35830661E-18	.16739434E-17	20

TAU(2,1)
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	.14740481E-21	.14741507E-21	4
.20	.52113665E-22	.52120913E-22	4
.50	.13182255E-22	.13185745E-22	4
1.00	.46594856E-23	.46719289E-23	4
2.00	.16693142E-23	.16380020E-23	4
5.00	.39026661E-24	.38849929E-24	4
10.00	.11229166E-24	.14829320E-24	4
20.00	.30548212E-25	.65544862E-25	4
50.00	.54123274E-26	.24634377E-25	4
100.00	.14707257E-26	.12065752E-25	4
200.00	.40010339E-27	.59661922E-26	4
500.00	.71424271E-28	.23686312E-26	4
1000.00	.18908236E-28	.11812421E-26	4
2000.00	.48944251E-29	.59002164E-27	4
5000.00	.81574344E-30	.23590204E-27	4
10000.00	.21025751E-30	.11793473E-27	4

TAU(2,1)
R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	.74159758E-22	.74159692E-22	20
.20	.26219445E-22	.26219398E-22	20
.50	.66329604E-23	.66323783E-23	20
1.00	.23449635E-23	.23495586E-23	20
2.00	.84034124E-24	.82335118E-24	20
5.00	.19645877E-24	.19544706E-24	20
10.00	.57023685E-25	.74928255E-25	20
20.00	.16200721E-25	.33132597E-25	20
50.00	.35589164E-26	.12207334E-25	20
100.00	.13678587E-26	.57056020E-26	20
200.00	.56189651E-27	.26172998E-26	20
500.00	.15715574E-27	.93683684E-27	20
1000.00	.53101210E-28	.44188692E-27	20
2000.00	.16330453E-28	.21371060E-27	20
5000.00	.30840175E-29	.83892372E-28	20
10000.00	.82695838E-30	.41740270E-28	20

TAU(2,1)
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL PART	IMAGINARY PART	J
.10	.29481434E-22	.29481415E-22	20
.20	.10423264E-22	.10423251E-22	20
.50	.26368616E-23	.26366363E-23	20
1.00	.93221418E-24	.93404425E-24	20
2.00	.33406781E-24	.32731609E-24	20
5.00	.78100422E-25	.77697936E-25	20
10.00	.22668983E-25	.29785178E-25	20
20.00	.64370523E-26	.13165942E-25	20
50.00	.13932763E-26	.48646503E-26	20
100.00	.54772965E-27	.23102578E-26	20
200.00	.26726698E-27	.10670439E-26	20
500.00	.10289351E-27	.35838822E-27	20
1000.00	.41904208E-28	.15495673E-27	20
2000.00	.14602076E-28	.69372333E-28	20
5000.00	.30352510E-29	.25700048E-28	20
10000.00	.84649945E-30	.12559970E-28	20

APPENDIX X

Field strengths of all dipole components on the surface of the earth. See front page of Appendix IX for meaning of symbols.

C F(PHI) V. M. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .18857319E-10

T	REAL ET	IMAG. ET	ABS. ET
.10	.15080830E-16	-.15286509E-16	.21473443E-16
.20	.10603705E-16	-.10808561E-16	.15141451E-16
.50	.66307640E-17	-.68345817E-17	.95225279E-17
1.00	.46385492E-17	-.48316426E-17	.66978286E-17
2.00	.31893091E-17	-.34554776E-17	.47023417E-17
5.00	.18478846E-17	-.20160405E-17	.27347937E-17
10.00	.14087949E-17	-.12286215E-17	.18692816E-17
20.00	.12101027E-17	-.83919696E-18	.14726167E-17
50.00	.91176525E-18	-.71944177E-18	.11614268E-17
100.00	.57651868E-18	-.66091860E-18	.87703317E-18
200.00	.27526600E-18	-.50448133E-18	.57469364E-18
500.00	.71226686E-19	-.26481567E-18	.27422723E-18
1000.00	.21337512E-19	-.14288953E-18	.14447389E-18
2000.00	.58125613E-20	-.73513153E-19	.73742589E-19
5000.00	.97020384E-21	-.29705449E-19	.29721288E-19
10000.00	.24736993E-21	-.14879881E-19	.14881937E-19

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .94868334E-11

T	REAL ET	IMAG. ET	ABS. ET
.10	.80124852E-18	-.79980311E-18	.11321149E-17
.20	.56698392E-18	-.56557319E-18	.80083943E-18
.50	.35907567E-18	-.35768455E-18	.50682697E-18
1.00	.25482394E-18	-.25291334E-18	.35902700E-18
2.00	.17902575E-18	-.18130684E-18	.25479872E-18
5.00	.10659196E-18	-.10599051E-18	.15031910E-18
10.00	.81765614E-19	-.61215223E-19	.10214166E-18
20.00	.72186141E-19	-.33956821E-19	.79774085E-19
50.00	.66033826E-19	-.15163284E-19	.67752426E-19
100.00	.65631789E-19	-.38463084E-20	.65744396E-19
200.00	.79167424E-19	-.29067153E-20	.79220766E-19
500.00	.70330161E-19	-.38702289E-19	.80275766E-19
1000.00	.35867907E-19	-.44233844E-19	.56948571E-19
2000.00	.13027798E-19	-.30901343E-19	.33535302E-19
5000.00	.26120870E-20	-.14305968E-19	.14542479E-19
10000.00	.70468368E-21	-.73806934E-20	.74142574E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .37714640E-11

T	REAL ET	IMAG. ET	ABS. ET
.10	.12238875E-18	-.12778116E-18	.17693792E-18
.20	.86648968E-19	-.89191705E-19	.12435112E-18
.50	.54928723E-19	-.55734349E-19	.78252682E-19
1.00	.39026008E-19	-.39169162E-19	.55292428E-19
2.00	.27461951E-19	-.27958397E-19	.39189675E-19
5.00	.16393021E-19	-.16286864E-19	.23108290E-19
10.00	.12599379E-19	-.93638260E-20	.15697948E-19
20.00	.11159903E-19	-.51279899E-20	.12281681E-19
50.00	.10350670E-19	-.23054471E-20	.10604312E-19
100.00	.96416772E-20	-.10560052E-20	.96993343E-20
200.00	.92741026E-20	.17363871E-20	.94352540E-20
500.00	.16422657E-19	.13141927E-20	.16475155E-19
1000.00	.14818090E-19	-.67614216E-20	.16287805E-19
2000.00	.74326995E-20	-.86843025E-20	.11430753E-19
5000.00	.18309103E-20	-.51809254E-20	.54949267E-20
10000.00	.53150997E-21	-.28387558E-20	.28880854E-20

C H(RO) V. M. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,1)= .54396117F-15

T	REAL RH	IMAG. HR	ABS. HR
.10	-.10805528E-14	.72471521E-17	.10805771E-14
.20	-.10775011E-14	.10177520E-16	.10775491E-14
.50	-.10714495E-14	.15867637E-16	.10715669E-14
1.00	-.10646341E-14	.22131818E-16	.10648641E-14
2.00	-.10546353E-14	.30290959E-16	.10550701E-14
5.00	-.10393922E-14	.43661379E-16	.10403088E-14
10.00	-.10279452E-14	.66418318E-16	.10300886E-14
20.00	-.10029784E-14	.11206009E-15	.10092190E-14
50.00	-.90514394E-15	.19357867E-15	.92561236E-15
100.00	-.77666536E-15	.21676833E-15	.80634829E-15
200.00	-.65713096E-15	.17932948E-15	.68116089E-15
500.00	-.57401729E-15	.98242985E-16	.58236374E-15
1000.00	-.55314602E-15	.53749339E-16	.55575130E-15
2000.00	-.54649758E-15	.27828650E-16	.54720565E-15
5000.00	-.54439214E-15	.11275332E-16	.54450888E-15
10000.00	-.54407374E-15	.56529726E-17	.54410309E-15

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,1)= .28460501E-16

T	REAL RH	IMAG. HR	ABS. HR
.10	-.56971616E-16	-.50221658E-19	.56971637E-16
.20	-.56992598E-16	-.70781772E-19	.56992641E-16
.50	-.57034211E-16	-.11114341E-18	.57034318E-16
1.00	-.57081092E-16	-.15627925E-18	.57081306E-16
2.00	-.57150319E-16	-.21653945E-18	.57150728E-16
5.00	-.57256161E-16	-.31561668E-18	.57257031E-16
10.00	-.57318996E-16	-.47981124E-18	.57321004E-16
20.00	-.57409461E-16	-.84266120E-18	.57415644E-16
50.00	-.57841780E-16	-.20451909E-17	.57877925E-16
100.00	-.60117493E-16	-.40478249E-17	.60253612E-16
200.00	-.67740209E-16	-.13511266E-17	.67753681E-16
500.00	-.63363589E-16	.17768060E-16	.65807661E-16
1000.00	-.46676613E-16	.21193152E-16	.51262616E-16
2000.00	-.35318527E-16	.15166675E-16	.38437303E-16
5000.00	-.29912331E-16	.71724933E-17	.30760237E-16
10000.00	-.28868596E-16	.37347085E-17	.29109171E-16

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,1)= .43516893E-17

T	REAL RH	IMAG. HR	ABS. HR
.10	-.87069417E-17	-.12885695E-19	.87069512E-17
.20	-.87122952E-17	-.18194905E-19	.87123142E-17
.50	-.87229225E-17	-.28678625E-19	.87229696E-17
1.00	-.87348907E-17	-.40498985E-19	.87349846E-17
2.00	-.87525778E-17	-.56483604E-19	.87527600E-17
5.00	-.87796178E-17	-.83228622E-19	.87800123E-17
10.00	-.87946095E-17	-.12696343E-18	.87955258E-17
20.00	-.88123611E-17	-.22211580E-18	.88151598E-17
50.00	-.88679834E-17	-.50018003E-18	.88820780E-17
100.00	-.89544104E-17	-.96950058E-18	.90067417E-17
200.00	-.96131202E-17	-.21960712E-17	.98607711E-17
500.00	-.13819228E-16	-.98398872E-18	.13854215E-16
1000.00	-.12832837E-16	.36249968E-17	.13335003E-16
2000.00	-.87507055E-17	.48286122E-17	.99945156E-17
5000.00	-.55147264E-17	.29920078E-17	.62740988E-17
10000.00	-.47099959E-17	.16739434E-17	.49986145E-17

C H(Z) OF A V. M. D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,0)= .20000000E-14

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.21349200E-16	.21047211E-16	.29979550E-16
.20	.30190100E-16	.29589157E-16	.42272453E-16
.50	.47724100E-16	.46230724E-16	.66444484E-16
1.00	.67474400E-16	.64639369E-16	.93440048E-16
2.00	.96496500E-16	.88800315E-16	.13113759E-15
5.00	.14073820E-15	.12850045E-15	.19057703E-15
10.00	.17205230E-15	.19579786E-15	.26065071E-15
20.00	.23667560E-15	.33495427E-15	.41013375E-15
50.00	.50593290E-15	.62118505E-15	.80114853E-15
100.00	.91528340E-15	.77326635E-15	.11982005E-14
200.00	.13772349E-14	.72838315E-15	.15579852E-14
500.00	.17864976E-14	.46707445E-15	.18465460E-14
1000.00	.19237492E-14	.27875003E-15	.19438396E-14
2000.00	.19759599E-14	.15050679E-15	.19816835E-14
5000.00	.19944886E-14	.62967725E-16	.19954823E-14
10000.00	.19981878E-14	.32251456E-16	.19984480E-14

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,0)= .17769398E-14

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.17494000E-16	.17271179E-16	.24583198E-16
.20	.24738900E-16	.24294979E-16	.34673608E-16
.50	.39109000E-16	.38003712E-16	.54532522E-16
1.00	.55296700E-16	.53207651E-16	.76738380E-16
2.00	.79107600E-16	.73243880E-16	.10780852E-15
5.00	.11539420E-15	.10620490E-15	.15682889E-15
10.00	.14019850E-15	.16204862E-15	.21427872E-15
20.00	.19005360E-15	.27960313E-15	.33808028E-15
50.00	.40826740E-15	.53537890E-15	.67328511E-15
100.00	.76286300E-15	.68845441E-15	.10275842E-14
200.00	.11831870E-14	.66649323E-15	.13579928E-14
500.00	.15713573E-14	.43658985E-15	.16308815E-14
1000.00	.17014623E-14	.26131023E-15	.17214113E-14
2000.00	.17521094E-14	.14331561E-15	.17579609E-14
5000.00	.17719723E-14	.60232757E-16	.17729956E-14
10000.00	.17754373E-14	.30523883E-16	.17756996E-14

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,0)=-.22135945E-16

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	-.84385000E-19	-.84434675E-19	.11937353E-18
.20	-.11934200E-18	-.11943250E-18	.16883908E-18
.50	-.18872800E-18	-.18889501E-18	.26701981E-18
1.00	-.26687500E-18	-.26778590E-18	.37806289E-18
2.00	-.38258400E-18	-.37560499E-18	.53614329E-18
5.00	-.55926900E-18	-.55750119E-18	.78967676E-18
10.00	-.64832500E-18	-.85363732E-18	.10719243E-17
20.00	-.72773100E-18	-.15012673E-17	.16683512E-17
50.00	-.78268400E-18	-.34613961E-17	.35487824E-17
100.00	-.70959300E-18	-.76219350E-17	.76548948E-17
200.00	-.62468660E-17	-.17092902E-16	.18198643E-16
500.00	-.27358012E-16	-.15555217E-16	.31471027E-16
1000.00	-.31744096E-16	-.38133709E-17	.31972320E-16
2000.00	-.28190227E-16	.20451163E-17	.28264313E-16
5000.00	-.24107530E-16	.25454967E-17	.24241545E-16
10000.00	-.22850178E-16	.16613346E-17	.22910492E-16

HZ V.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
N(2,0)=-.66725903E-17

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.31056000E-20	-.92398646E-20	.97478125E-20
.20	-.71650000E-21	-.13065752E-19	.13085383E-19
.50	-.83090000E-20	-.20652605E-19	.22261391E-19
1.00	-.16867400E-19	-.29258814E-19	.33772582E-19
2.00	-.29518400E-19	-.41003530E-19	.50523513E-19
5.00	-.48840300E-19	-.60900053E-19	.78065302E-19
10.00	-.58966600E-19	-.93162464E-19	.11025563E-18
20.00	-.68311700E-19	-.16269451E-18	.17645393E-18
50.00	-.84083900E-19	-.36651433E-18	.37603570E-18
100.00	-.49680000E-19	-.65683605E-18	.65871215E-18
200.00	.41711490E-18	-.15989267E-17	.16524380E-17
500.00	-.21862384E-17	-.58125456E-17	.62100985E-17
1000.00	-.72504855E-17	-.48729947E-17	.87358810E-17
2000.00	-.87637813E-17	-.15949791E-17	.89077393E-17
5000.00	-.77890556E-17	.32083186E-18	.77956603E-17
10000.00	-.71529027E-17	.45827449E-18	.71675680E-17

E(X)=0 AT THETA=0 AND 90 DEGREES
E(X)=0 AT R=0 FOR ALL ANGLES

C E(X) H. M. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,0)= .94286599E-10 N(0,1)= .97097000E-06

T	REAL EX	IMAG. EX	ABS. EX
.10	.13013855E-17	-.13371199E-17	.18658761E-17
.20	.91366401E-18	-.94268348E-18	.13127962E-17
.50	.56962233E-18	-.59430661E-18	.82320711E-18
1.00	.39711481E-18	-.41946671E-18	.57762660E-18
2.00	.27162192E-18	-.29952674E-18	.40434481E-18
5.00	.15652954E-18	-.17456701E-18	.23446777E-18
10.00	.11899918E-18	-.10800480E-18	.16070420E-18
20.00	.10013506E-18	-.76668079E-19	.12611512E-18
50.00	.68626548E-19	-.65757237E-19	.95045343E-19
100.00	.38183256E-19	-.55539786E-19	.67399026E-19
200.00	.15718870E-19	-.38466750E-19	.41554466E-19
500.00	.35502449E-20	-.17483000E-19	.17839829E-19
1000.00	.13966401E-20	-.10078641E-19	.10174949E-19
2000.00	-.26659463E-21	-.49470187E-20	.49541968E-20
5000.00	.22131251E-22	-.17156152E-20	.17157579E-20
10000.00	.71668843E-22	-.91937544E-21	.92216463E-21

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	.13013855E-17	-.13371199E-17	.18658761E-17
.20	.91366404E-18	-.94268351E-18	.13127962E-17
.50	.56962235E-18	-.59430663E-18	.82320713E-18
1.00	.39711483E-18	-.41946673E-18	.57762663E-18
2.00	.27162193E-18	-.29952675E-18	.40434482E-18
5.00	.15652954E-18	-.17456702E-18	.23446778E-18
10.00	.11899919E-18	-.10800481E-18	.16070421E-18
20.00	.10013506E-18	-.76668081E-19	.12611512E-18
50.00	.68626550E-19	-.65757239E-19	.95045346E-19
100.00	.38183258E-19	-.55539788E-19	.67399030E-19
200.00	.15718870E-19	-.38466751E-19	.41554466E-19
500.00	.35502450E-20	-.17483000E-19	.17839829E-19
1000.00	.13966402E-20	-.10078641E-19	.10174949E-19
2000.00	-.26659464E-21	-.49470188E-20	.49541969E-20
5000.00	.22131252E-22	-.17156153E-20	.17157580E-20
10000.00	.71668845E-22	-.91937548E-21	.92216467E-21

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,0)= .31622778E-11 N(0,1)= .22792410E-05

T	REAL EX	IMAG. EX	ABS. EX
.10	.10371650E-17	-.10390945E-17	.14681378E-17
.20	.73284374E-18	-.73479178E-18	.10377759E-17
.50	.46276597E-18	-.46467663E-18	.65580234E-18
1.00	.32733298E-18	-.32856801E-18	.46379286E-18
2.00	.22885164E-18	-.23543918E-18	.32833623E-18
5.00	.13529431E-18	-.13762491E-18	.19299006E-18
10.00	.10350534E-18	-.80287584E-19	.13099408E-18
20.00	.91282041E-19	-.46422388E-19	.10240824E-18
50.00	.84140557E-19	-.26803277E-19	.88306562E-19
100.00	.81455138E-19	-.24184900E-19	.84969693E-19
200.00	.74773951E-19	-.35077433E-19	.82592796E-19
500.00	.39046427E-19	-.45406423E-19	.59886281E-19
1000.00	.15005480E-19	-.33323589E-19	.36546217E-19
2000.00	.45438336E-20	-.19255330E-19	.19784189E-19
5000.00	.79535363E-21	-.81262144E-20	.81650442E-20
10000.00	.20309913E-21	-.41008605E-20	.41058867E-20

C E(X) H. M. D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

N(1,0)= .31622778E-11 N(0,1)= .22792410E-05

T	REAL EX	IMAG. EX	ABS. EX
.10	.10371651E-17	-.10390945E-17	.14681378E-17
.20	.73284377E-18	-.73479181E-18	.10377759E-17
.50	.46276598E-18	-.46467665E-18	.65580236E-18
1.00	.32733299E-18	-.32856802E-18	.46379287E-18
2.00	.22885165E-18	-.23543919E-18	.32833624E-18
5.00	.13529431E-18	-.13762492E-18	.19299007E-18
10.00	.10350534E-18	-.80287587E-19	.13099408E-18
20.00	.91282044E-19	-.46422389E-19	.10240824E-18
50.00	.84140560E-19	-.26803278E-19	.88306565E-19
100.00	.81455141E-19	-.24184900E-19	.84969696E-19
200.00	.74773954E-19	-.35077434E-19	.82592799E-19
500.00	.39046428E-19	-.45406424E-19	.59886282E-19
1000.00	.15005481E-19	-.33323590E-19	.36546218E-19
2000.00	.45438338E-20	-.19255330E-19	.19784189E-19
5000.00	.79535366E-21	-.81262147E-20	.81650445E-20
10000.00	.20309914E-21	-.41008606E-20	.41058868E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,0)= .75429281E-12 N(0,1)= .16077678E-05

T	REAL EX	IMAG. EX	ABS. EX
.10	.26473433E-18	-.26160258E-18	.37218297E-18
.20	.18714078E-18	-.18565542E-18	.26360881E-18
.50	.11827734E-18	-.11779910E-18	.16693159E-18
1.00	.83747369E-19	-.83443112E-19	.11822171E-18
2.00	.58638187E-19	-.59871338E-19	.83803425E-19
5.00	.34745768E-19	-.35025035E-19	.49335803E-19
10.00	.26612305E-19	-.20378328E-19	.33518517E-19
20.00	.23494742E-19	-.11655420E-19	.26226927E-19
50.00	.21599268E-19	-.64798936E-20	.22550330E-19
100.00	.20369190E-19	-.50413301E-20	.20983777E-19
200.00	.19800461E-19	-.47758206E-20	.20368277E-19
500.00	.17108007E-19	-.97530570E-20	.19692791E-19
1000.00	.93440904E-20	-.11217746E-19	.14599652E-19
2000.00	.34472907E-20	-.80347249E-20	.87430324E-20
5000.00	.67441465E-21	-.37309888E-20	.37914524E-20
10000.00	.17765497E-21	-.19193793E-20	.19275834E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	.26473434E-18	-.26160259E-18	.37218299E-18
.20	.18714078E-18	-.18565543E-18	.26360882E-18
.50	.11827734E-18	-.11779910E-18	.16693159E-18
1.00	.83747372E-19	-.83443115E-19	.11822171E-18
2.00	.58638189E-19	-.59871340E-19	.83803428E-19
5.00	.34745769E-19	-.35025036E-19	.49335804E-19
10.00	.26612306E-19	-.20378329E-19	.33518518E-19
20.00	.23494743E-19	-.11655421E-19	.26226928E-19
50.00	.21599269E-19	-.64798938E-20	.22550331E-19
100.00	.20369191E-19	-.50413303E-20	.20983778E-19
200.00	.19800461E-19	-.47758208E-20	.20368277E-19
500.00	.17108007E-19	-.97530574E-20	.19692791E-19
1000.00	.93440907E-20	-.11217746E-19	.14599652E-19
2000.00	.34472909E-20	-.80347252E-20	.87430328E-20
5000.00	.67441468E-21	-.37309889E-20	.37914526E-20
10000.00	.17765497E-21	-.19193794E-20	.19275835E-20

C E(Y) H. M. D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,0)= .10000000E-09

T	REAL EY	IMAG. EY	ABS. EY
.10	-.27804274E-16	.28102535E-16	.39532646E-16
.20	-.19573482E-16	.19870684E-16	.27892028E-16
.50	-.12269328E-16	.12565502E-16	.17562125E-16
1.00	-.86066250E-17	.88837485E-17	.12369113E-16
2.00	-.59423795E-17	.63569920E-17	.87019090E-17
5.00	-.34590820E-17	.37107081E-17	.50729284E-17
10.00	-.26401554E-17	.22349184E-17	.34590865E-17
20.00	-.22937039E-17	.14701664E-17	.27244204E-17
50.00	-.18507827E-17	.12171338E-17	.22151323E-17
100.00	-.13135360E-17	.11840813E-17	.17684527E-17
200.00	-.73533545E-18	.10050115E-17	.12452976E-17
500.00	-.24164020E-18	.60460390E-18	.65110357E-18
1000.00	-.83630415E-19	.35161573E-18	.36142448E-18
2000.00	-.25151630E-19	.18748909E-18	.18916860E-18
5000.00	-.50095505E-20	.77383480E-19	.77545460E-19
10000.00	-.14625058E-20	.39157141E-19	.39184443E-19

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,1)= .97097000E-06 N(1,0)= .94286599E-10

T	REAL EY	IMAG. EY	ABS. EY
.10	.23221127E-16	-.23425124E-16	.32984194E-16
.20	.16355942E-16	-.16566492E-16	.23280152E-16
.50	.10263546E-16	-.10478339E-16	.14667514E-16
1.00	.72084307E-17	-.74091668E-17	.10337176E-16
2.00	.49861962E-17	-.53035104E-17	.72793801E-17
5.00	.29081462E-17	-.30964597E-17	.42479850E-17
10.00	.22213876E-17	-.18546204E-17	.28938174E-17
20.00	.19416244E-17	-.11998997E-17	.22824689E-17
50.00	.16101212E-17	-.98556870E-18	.18878124E-17
100.00	.11799267E-17	-.98870322E-18	.15394028E-17
200.00	.68110607E-18	-.87044248E-18	.11052490E-17
500.00	.22809380E-18	-.54219329E-18	.58821793E-18
1000.00	.80072102E-19	-.31624270E-18	.32622230E-18
2000.00	.25933837E-19	-.17078978E-18	.17274753E-18
5000.00	.47830810E-20	-.71267683E-19	.71428008E-19
10000.00	.12328624E-20	-.35874642E-19	.35895818E-19

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	.23972483E-16	-.24197072E-16	.34061388E-16
.20	.16883446E-16	-.17110781E-16	.24038086E-16
.50	.10592419E-16	-.10821442E-16	.15142752E-16
1.00	.74377053E-17	-.76513422E-17	.10670636E-16
2.00	.51430174E-17	-.54764402E-17	.75127907E-17
5.00	.29985186E-17	-.31972441E-17	.43833187E-17
10.00	.22900918E-17	-.19169772E-17	.29865234E-17
20.00	.19994374E-17	-.12441639E-17	.23549296E-17
50.00	.16497429E-17	-.10235336E-17	.19414614E-17
100.00	.12019719E-17	-.10207690E-17	.15769292E-17
200.00	.69018138E-18	-.89265128E-18	.11283512E-17
500.00	.23014355E-18	-.55228711E-18	.59832023E-18
1000.00	.80878460E-19	-.32206161E-18	.33206174E-18
2000.00	.25779917E-19	-.17364595E-18	.17554919E-18
5000.00	.47958586E-20	-.72258195E-19	.72417172E-19
10000.00	.12742404E-20	-.36405444E-19	.36427736E-19

C F(Y) H. M. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

N(0,1)= .97097000E-06 N(1,0)= .94286599E-10

T	REAL EY	IMAG. EY	ABS. EY
.10	.25475192E-16	-.25741045E-16	.36215836E-16
.20	.17938453E-16	-.18199278E-16	.25553900E-16
.50	.11250161E-16	-.11507680E-16	.16093253E-16
1.00	.78962536E-17	-.81357006E-17	.11337567E-16
2.00	.54566590E-17	-.58222960E-17	.79796151E-17
5.00	.31792631E-17	-.33988144E-17	.46539932E-17
10.00	.24275002E-17	-.20416900E-17	.31719481E-17
20.00	.21150634E-17	-.13326918E-17	.24999121E-17
50.00	.17289859E-17	-.10994632E-17	.20489537E-17
100.00	.12460620E-17	-.10849007E-17	.16521743E-17
200.00	.70833192E-18	-.93706884E-18	.11746625E-17
500.00	.23424301E-18	-.57247473E-18	.61854433E-18
1000.00	.82491153E-19	-.33369942E-18	.34374422E-18
2000.00	.25472079E-19	-.17935826E-18	.18115797E-18
5000.00	.48214137E-20	-.74239218E-19	.74395614E-19
10000.00	.13569964E-20	-.37467046E-19	.37491611E-19

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	.26226547E-16	-.26513070E-16	.37293090E-16
.20	.18465957E-16	-.18743566E-16	.26311838E-16
.50	.11579032E-16	-.11850800E-16	.16568507E-16
1.00	.81255279E-17	-.83778838E-17	.11671038E-16
2.00	.56134802E-17	-.59952337E-17	.82130376E-17
5.00	.32696356E-17	-.34996019E-17	.47893350E-17
10.00	.24962044E-17	-.21040476E-17	.32646672E-17
20.00	.21728763E-17	-.13769563E-17	.25724307E-17
50.00	.17686074E-17	-.11374282E-17	.21027874E-17
100.00	.12681071E-17	-.11169667E-17	.16898846E-17
200.00	.71740723E-18	-.95927768E-18	.11978676E-17
500.00	.23629272E-18	-.58256854E-18	.62866553E-18
1000.00	.83297503E-19	-.33951833E-18	.34958714E-18
2000.00	.25318161E-19	-.18221443E-18	.18396496E-18
5000.00	.48341912E-20	-.75229728E-19	.75384888E-19
10000.00	.13983745E-20	-.37997848E-19	.38023570E-19

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,1)= .22792410E-05 N(1,0)= .31622778E-11

T	REAL EY	IMAG. EY	ABS. EY
.10	-.15074789E-17	.15108804E-17	.21343036E-17
.20	-.10649737E-17	.10683971E-17	.15085229E-17
.50	-.67226198E-18	.67568342E-18	.95314440E-18
1.00	-.47533074E-18	.47775968E-18	.67393888E-18
2.00	-.33212919E-18	.34232934E-18	.47696874E-18
5.00	-.19617502E-18	.20011150E-18	.28023070E-18
10.00	-.15001356E-18	.11687691E-18	.19016908E-18
20.00	-.13223834E-18	.67864991E-19	.14863591E-18
50.00	-.12205051E-18	.39780747E-19	.12836991E-18
100.00	-.11909252E-18	.37811424E-19	.12495091E-18
200.00	-.10656548E-18	.59336256E-19	.12197127E-18
500.00	-.42840972E-19	.70206670E-19	.82245519E-19
1000.00	-.96995867E-20	.44085253E-19	.45139687E-19
2000.00	-.47887921E-21	.21637430E-19	.21642728E-19
5000.00	.48768377E-21	.78121455E-20	.78273528E-20
10000.00	.22353599E-21	.37013269E-20	.37080707E-20

C E(Y) H. M. D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(0,1)= .22792410E-05 N(1,0)= .31622778E-11

T	REAL EY	IMAG. EY	ABS. EY
.10	-.90867126E-18	.91095906E-18	.12866739E-17
.20	-.64186613E-18	.64416188E-18	.90936057E-18
.50	-.40508390E-18	.40739908E-18	.57451456E-18
1.00	-.28634495E-18	.28806165E-18	.40616861E-18
2.00	-.20000162E-18	.20639788E-18	.28740343E-18
5.00	-.11806283E-18	.12065387E-18	.16880813E-18
10.00	-.90254726E-19	.70522737E-19	.11453982E-18
20.00	-.79536626E-19	.41063015E-19	.89511150E-19
50.00	-.73471932E-19	.24305856E-19	.77387979E-19
100.00	-.72064374E-19	.23848258E-19	.75907927E-19
200.00	-.63394716E-19	.39084291E-19	.74474638E-19
500.00	-.20297507E-19	.43991258E-19	.48448111E-19
1000.00	-.10361679E-20	.24845870E-19	.24867466E-19
2000.00	.21445049E-20	.10520361E-19	.10736708E-19
5000.00	.94688148E-21	.31204732E-20	.32609717E-20
10000.00	.34079530E-21	.13336940E-20	.13765468E-20

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	.28894357E-18	-.28887120E-18	.40857673E-18
.20	.20434879E-18	-.20428755E-18	.28894953E-18
.50	.12927214E-18	-.12916314E-18	.18274135E-18
1.00	.91626554E-19	-.91332765E-19	.12937194E-18
2.00	.64253451E-19	-.65464011E-19	.91728091E-19
5.00	.38161565E-19	-.38261037E-19	.54038985E-19
10.00	.29262927E-19	-.22185413E-19	.36722083E-19
20.00	.25866777E-19	-.12540936E-19	.28746569E-19
50.00	.23685202E-19	-.66438396E-20	.24599377E-19
100.00	.21991906E-19	-.40780212E-20	.22366809E-19
200.00	.22946791E-19	-.14196274E-20	.22990662E-19
500.00	.24789414E-19	-.84395538E-20	.26186659E-19
1000.00	.16290665E-19	-.13632887E-19	.21242442E-19
2000.00	.73912707E-20	-.11713772E-19	.13850751E-19
5000.00	.18652766E-20	-.62628691E-20	.65347367E-20
10000.00	.57531394E-21	-.34015708E-20	.34498797E-20

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	.88775121E-18	-.88878947E-18	.12562041E-17
.20	.62745638E-18	-.62850811E-18	.88810131E-18
.50	.39645023E-18	-.39744133E-18	.56136653E-18
1.00	.28061237E-18	-.28103088E-18	.39714185E-18
2.00	.19638102E-18	-.20139413E-18	.28129184E-18
5.00	.11627378E-18	-.11771867E-18	.16546080E-18
10.00	.89021775E-19	-.68539320E-19	.11234996E-18
20.00	.78568493E-19	-.39342917E-19	.87868499E-19
50.00	.72263785E-19	-.22118674E-19	.75573079E-19
100.00	.69020062E-19	-.18041193E-19	.71339004E-19
200.00	.66117559E-19	-.21671594E-19	.69578656E-19
500.00	.47332884E-19	-.34654968E-19	.58663180E-19
1000.00	.24954083E-19	-.32872271E-19	.41270963E-19
2000.00	.10014655E-19	-.22830842E-19	.24930717E-19
5000.00	.23244743E-20	-.10954542E-19	.11198444E-19
10000.00	.69257329E-21	-.57692039E-20	.58106256E-20

E(Y) H.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(0,1)= .16077678E-05 N(1,0)= .75429281E-12

T	REAL EY	IMAG. EY	ABS. EY
.10	-.39949259E-18	.39210153E-18	.55976596E-18
.20	-.28238303E-18	.27882616E-18	.39684279E-18
.50	-.17844955E-18	.17724468E-18	.25151524E-18
1.00	-.12633384E-18	.12566419E-18	.17819014E-18
2.00	-.88437178E-19	.90222863E-19	.12633803E-18
5.00	-.52385599E-19	.52807079E-19	.74383053E-19
10.00	-.40114788E-19	.30742809E-19	.50540246E-19
20.00	-.35406079E-19	.17613794E-19	.39545367E-19
50.00	-.32522424E-19	.98556396E-20	.33982961E-19
100.00	-.30660897E-19	.76638074E-20	.31604185E-19
200.00	-.30262823E-19	.74391470E-20	.31163750E-19
500.00	-.25074772E-19	.16959600E-19	.30271640E-19
1000.00	-.11201027E-19	.17940475E-19	.21150027E-19
2000.00	-.27334055E-20	.11240581E-19	.11568152E-19
5000.00	-.11029988E-21	.44328404E-20	.44342124E-20
10000.00	.55415100E-22	.21030402E-20	.21037701E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	-.24664815E-18	.24106403E-18	.34488718E-18
.20	-.17433724E-18	.17163737E-18	.24464844E-18
.50	-.11016211E-18	.10923310E-18	.15513722E-18
1.00	-.77982286E-19	.77488187E-19	.10993478E-18
2.00	-.54582402E-19	.55656082E-19	.77954076E-19
5.00	-.32325121E-19	.32585354E-19	.45899005E-19
10.00	-.24750167E-19	.18977370E-19	.31188320E-19
20.00	-.21841382E-19	.10884531E-19	.24403257E-19
50.00	-.20052080E-19	.61144691E-20	.20963602E-19
100.00	-.18900740E-19	.47531929E-20	.19489248E-19
200.00	-.18831020E-19	.46818252E-20	.19404298E-19
500.00	-.15197461E-19	.11328670E-19	.18955252E-19
1000.00	-.58062144E-20	.11463906E-19	.12850418E-19
2000.00	-.74311092E-21	.66017298E-20	.66434214E-20
5000.00	.27907362E-21	.22787527E-20	.22957778E-20
10000.00	.15798425E-21	.99488590E-21	.10073514E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL EY	IMAG. EY	ABS. EY
.10	.59040677E-19	-.61004664E-19	.84896233E-19
.20	.41754279E-19	-.42737067E-19	.59748445E-19
.50	.26412775E-19	-.26788787E-19	.37620123E-19
1.00	.18720832E-19	-.18863260E-19	.26576157E-19
2.00	.13127130E-19	-.13477203E-19	.18813732E-19
5.00	.77958281E-20	-.78580157E-20	.11069026E-19
10.00	.59790707E-20	-.45534684E-20	.75155412E-20
20.00	.52880058E-20	-.25739740E-20	.58811858E-20
50.00	.48886031E-20	-.13678594E-20	.50763647E-20
100.00	.46195720E-20	-.10680298E-20	.47414272E-20
200.00	.40325798E-20	-.83281500E-21	.41176789E-20
500.00	.45571620E-20	.66812349E-22	.45576515E-20
1000.00	.49834103E-20	-.14892282E-20	.52011708E-20
2000.00	.32374769E-20	-.26759700E-20	.42002466E-20
5000.00	.10578204E-20	-.20294213E-20	.22885661E-20
10000.00	.36312250E-21	-.12214220E-20	.12742564E-20

E(Y) H.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES
N(0,1)= .16077678E-05 N(1,0)= .75429281E-12

T	REAL EY	IMAG. EY	ABS. EY
.10	.21188514E-18	-.21204454E-18	.29976357E-18
.20	.14980008E-18	-.14992704E-18	.21193909E-18
.50	.94700242E-19	-.94800836E-19	.13399751E-18
1.00	.67072405E-19	-.67039497E-19	.94831438E-19
2.00	.46981906E-19	-.48044104E-19	.67197733E-19
5.00	.27856309E-19	-.28079787E-19	.39553107E-19
10.00	.21343694E-19	-.16318931E-19	.26867466E-19
20.00	.18852705E-19	-.93032484E-20	.21023199E-19
50.00	.17358949E-19	-.51090346E-20	.18095174E-19
100.00	.16379731E-19	-.39786467E-20	.16856014E-19
200.00	.15464383E-19	-.35901379E-20	.15875648E-19
500.00	.14434477E-19	-.55641184E-20	.15469762E-19
1000.00	.10378224E-19	-.79657979E-20	.13082868E-19
2000.00	.52277712E-20	-.73148211E-20	.89908953E-20
5000.00	.14471940E-20	-.41835091E-20	.44267502E-20
10000.00	.46569166E-21	-.23295764E-20	.23756672E-20

E(Z) OF H.M.D. IS 0 AT THETA=0 FOR
ALL R

E(Z) OF A H.M.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,1)= .18857319E-10

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.14893443E-14	.14893442E-14
.20	.00000000E-99	.74467211E-15	.74467210E-15
.50	.00000000E-99	.29786883E-15	.29786883E-15
1.00	.00000000E-99	.14893443E-15	.14893442E-15
2.00	.00000000E-99	.74467211E-16	.74467210E-16
5.00	.00000000E-99	.29786883E-16	.29786883E-16
10.00	.00000000E-99	.14893443E-16	.14893442E-16
20.00	.00000000E-99	.74467211E-17	.74467210E-17
50.00	.00000000E-99	.29786883E-17	.29786883E-17
100.00	.00000000E-99	.14893443E-17	.14893442E-17
200.00	.00000000E-99	.74467211E-18	.74467210E-18
500.00	.00000000E-99	.29786883E-18	.29786883E-18
1000.00	.00000000E-99	.14893443E-18	.14893442E-18
2000.00	.00000000E-99	.74467211E-19	.74467210E-19
5000.00	.00000000E-99	.29786883E-19	.29786883E-19
10000.00	.00000000E-99	.14893443E-19	.14893442E-19

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.25796198E-14	.25796197E-14
.20	.00000000E-99	.12898099E-14	.12898099E-14
.50	.00000000E-99	.51592393E-15	.51592392E-15
1.00	.00000000E-99	.25796198E-15	.25796197E-15
2.00	.00000000E-99	.12898099E-15	.12898099E-15
5.00	.00000000E-99	.51592393E-16	.51592392E-16
10.00	.00000000E-99	.25796198E-16	.25796197E-16
20.00	.00000000E-99	.12898099E-16	.12898099E-16
50.00	.00000000E-99	.51592393E-17	.51592392E-17
100.00	.00000000E-99	.25796198E-17	.25796197E-17
200.00	.00000000E-99	.12898099E-17	.12898099E-17
500.00	.00000000E-99	.51592393E-18	.51592392E-18
1000.00	.00000000E-99	.25796198E-18	.25796197E-18
2000.00	.00000000E-99	.12898099E-18	.12898099E-18
5000.00	.00000000E-99	.51592393E-19	.51592392E-19
10000.00	.00000000E-99	.25796198E-19	.25796197E-19

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.29786885E-14	.29786885E-14
.20	.00000000E-99	.14893442E-14	.14893441E-14
.50	.00000000E-99	.59573767E-15	.59573766E-15
1.00	.00000000E-99	.29786885E-15	.29786885E-15
2.00	.00000000E-99	.14893442E-15	.14893441E-15
5.00	.00000000E-99	.59573767E-16	.59573766E-16
10.00	.00000000E-99	.29786885E-16	.29786885E-16
20.00	.00000000E-99	.14893442E-16	.14893441E-16
50.00	.00000000E-99	.59573767E-17	.59573766E-17
100.00	.00000000E-99	.29786885E-17	.29786885E-17
200.00	.00000000E-99	.14893442E-17	.14893441E-17
500.00	.00000000E-99	.59573767E-18	.59573766E-18
1000.00	.00000000E-99	.29786885E-18	.29786885E-18
2000.00	.00000000E-99	.14893442E-18	.14893441E-18
5000.00	.00000000E-99	.59573767E-19	.59573766E-19
10000.00	.00000000E-99	.29786885E-19	.29786885E-19

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(1,1)= .94868334E-11

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.74926669E-15	.74926668E-15
.20	.00000000E-99	.37463333E-15	.37463332E-15
.50	.00000000E-99	.14985333E-15	.14985333E-15
1.00	.00000000E-99	.74926669E-16	.74926668E-16
2.00	.00000000E-99	.37463333E-16	.37463332E-16
5.00	.00000000E-99	.14985333E-16	.14985333E-16
10.00	.00000000E-99	.74926669E-17	.74926668E-17
20.00	.00000000E-99	.37463333E-17	.37463332E-17
50.00	.00000000E-99	.14985333E-17	.14985333E-17
100.00	.00000000E-99	.74926669E-18	.74926668E-18
200.00	.00000000E-99	.37463333E-18	.37463332E-18
500.00	.00000000E-99	.14985333E-18	.14985333E-18
1000.00	.00000000E-99	.74926669E-19	.74926668E-19
2000.00	.00000000E-99	.37463333E-19	.37463332E-19
5000.00	.00000000E-99	.14985333E-19	.14985333E-19
10000.00	.00000000E-99	.74926669E-20	.74926668E-20

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.12977679E-14	.12977678E-14
.20	.00000000E-99	.64888394E-15	.64888394E-15
.50	.00000000E-99	.25955357E-15	.25955357E-15
1.00	.00000000E-99	.12977679E-15	.12977678E-15
2.00	.00000000E-99	.64888394E-16	.64888394E-16
5.00	.00000000E-99	.25955357E-16	.25955357E-16
10.00	.00000000E-99	.12977679E-16	.12977678E-16
20.00	.00000000E-99	.64888394E-17	.64888394E-17
50.00	.00000000E-99	.25955357E-17	.25955357E-17
100.00	.00000000E-99	.12977679E-17	.12977678E-17
200.00	.00000000E-99	.64888394E-18	.64888394E-18
500.00	.00000000E-99	.25955357E-18	.25955357E-18
1000.00	.00000000E-99	.12977679E-18	.12977678E-18
2000.00	.00000000E-99	.64888394E-19	.64888394E-19
5000.00	.00000000E-99	.25955357E-19	.25955357E-19
10000.00	.00000000E-99	.12977679E-19	.12977678E-19

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.14985334E-14	.14985334E-14
.20	.00000000E-99	.74926667E-15	.74926666E-15
.50	.00000000E-99	.29970666E-15	.29970665E-15
1.00	.00000000E-99	.14985334E-15	.14985334E-15
2.00	.00000000E-99	.74926667E-16	.74926666E-16
5.00	.00000000E-99	.29970666E-16	.29970665E-16
10.00	.00000000E-99	.14985334E-16	.14985334E-16
20.00	.00000000E-99	.74926667E-17	.74926666E-17
50.00	.00000000E-99	.29970666E-17	.29970665E-17
100.00	.00000000E-99	.14985334E-17	.14985334E-17
200.00	.00000000E-99	.74926667E-18	.74926666E-18
500.00	.00000000E-99	.29970666E-18	.29970665E-18
1000.00	.00000000E-99	.14985334E-18	.14985334E-18
2000.00	.00000000E-99	.74926667E-19	.74926666E-19
5000.00	.00000000E-99	.29970666E-19	.29970665E-19
10000.00	.00000000E-99	.14985334E-19	.14985334E-19

E(Z) OF A H.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(1,1)= .37714640E-11

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.29786887E-15	.29786887E-15
.20	.00000000E-99	.14893443E-15	.14893442E-15
.50	.00000000E-99	.59573770E-16	.59573770E-16
1.00	.00000000E-99	.29786887E-16	.29786887E-16
2.00	.00000000E-99	.14893443E-16	.14893442E-16
5.00	.00000000E-99	.59573770E-17	.59573770E-17
10.00	.00000000E-99	.29786887E-17	.29786887E-17
20.00	.00000000E-99	.14893443E-17	.14893442E-17
50.00	.00000000E-99	.59573770E-18	.59573770E-18
100.00	.00000000E-99	.29786887E-18	.29786887E-18
200.00	.00000000E-99	.14893443E-18	.14893442E-18
500.00	.00000000E-99	.59573770E-19	.59573770E-19
1000.00	.00000000E-99	.29786887E-19	.29786887E-19
2000.00	.00000000E-99	.14893443E-19	.14893442E-19
5000.00	.00000000E-99	.59573770E-20	.59573770E-20
10000.00	.00000000E-99	.29786887E-20	.29786887E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.51592398E-15	.51592397E-15
.20	.00000000E-99	.25796199E-15	.25796198E-15
.50	.00000000E-99	.10318479E-15	.10318479E-15
1.00	.00000000E-99	.51592398E-16	.51592397E-16
2.00	.00000000E-99	.25796199E-16	.25796198E-16
5.00	.00000000E-99	.10318479E-16	.10318479E-16
10.00	.00000000E-99	.51592398E-17	.51592397E-17
20.00	.00000000E-99	.25796199E-17	.25796198E-17
50.00	.00000000E-99	.10318479E-17	.10318479E-17
100.00	.00000000E-99	.51592398E-18	.51592397E-18
200.00	.00000000E-99	.25796199E-18	.25796198E-18
500.00	.00000000E-99	.10318479E-18	.10318479E-18
1000.00	.00000000E-99	.51592398E-19	.51592397E-19
2000.00	.00000000E-99	.25796199E-19	.25796198E-19
5000.00	.00000000E-99	.10318479E-19	.10318479E-19
10000.00	.00000000E-99	.51592398E-20	.51592397E-20

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL EZ	IMAG. EZ	ABS. EZ
.10	.00000000E-99	.59573774E-15	.59573773E-15
.20	.00000000E-99	.29786886E-15	.29786886E-15
.50	.00000000E-99	.11914754E-15	.11914753E-15
1.00	.00000000E-99	.59573774E-16	.59573773E-16
2.00	.00000000E-99	.29786886E-16	.29786886E-16
5.00	.00000000E-99	.11914754E-16	.11914753E-16
10.00	.00000000E-99	.59573774E-17	.59573773E-17
20.00	.00000000E-99	.29786886E-17	.29786886E-17
50.00	.00000000E-99	.11914754E-17	.11914753E-17
100.00	.00000000E-99	.59573774E-18	.59573773E-18
200.00	.00000000E-99	.29786886E-18	.29786886E-18
500.00	.00000000E-99	.11914754E-18	.11914753E-18
1000.00	.00000000E-99	.59573774E-19	.59573773E-19
2000.00	.00000000E-99	.29786886E-19	.29786886E-19
5000.00	.00000000E-99	.11914754E-19	.11914753E-19
10000.00	.00000000E-99	.59573774E-20	.59573773E-20

C H(X) H. M. D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(2,0)= .20000000E-14

T	REAL HX	IMAG. HX	ABS. HX
.10	-.19893254E-14	.10523605E-16	.19893532E-14
.20	-.19849049E-14	.14794578E-16	.19849600E-14
.50	-.19761379E-14	.23115362E-16	.19762730E-14
1.00	-.19662628E-14	.32319684E-16	.19665283E-14
2.00	-.19517517E-14	.44400157E-16	.19522566E-14
5.00	-.19296309E-14	.64250225E-16	.19307002E-14
10.00	-.19139738E-14	.97898930E-16	.19164759E-14
20.00	-.18816622E-14	.16747713E-15	.18891006E-14
50.00	-.17470335E-14	.31059252E-15	.17744277E-14
100.00	-.15423583E-14	.38663317E-15	.15900799E-14
200.00	-.13113825E-14	.36419157E-15	.13610141E-14
500.00	-.11067512E-14	.23353722E-15	.11311223E-14
1000.00	-.10381254E-14	.13937501E-15	.10474395E-14
2000.00	-.10120200E-14	.75253395E-16	.10148140E-14
5000.00	-.10027557E-14	.31483862E-16	.10032498E-14
10000.00	-.10009061E-14	.16125728E-16	.10010359E-14

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,0)= .98058067E-05 N(2,0)= .17769398E-14 N(1,1)= .18857319E-1(

T	REAL HX	IMAG. HX	ABS. HX
.10	-.16603313E-14	.77238890E-17	.16603492E-14
.20	-.16570941E-14	.10869107E-16	.16571297E-14
.50	-.16506728E-14	.17014871E-16	.16507604E-14
1.00	-.16434390E-14	.23842177E-16	.16436119E-14
2.00	-.16327917E-14	.32862471E-16	.16331223E-14
5.00	-.16165688E-14	.47712460E-16	.16172727E-14
10.00	-.16057302E-14	.72861400E-16	.16073824E-14
20.00	-.15843490E-14	.12638608E-15	.15893820E-14
50.00	-.14876105E-14	.24677120E-15	.15079393E-14
100.00	-.13236955E-14	.32347510E-15	.13626466E-14
200.00	-.11237094E-14	.31796542E-15	.11678290E-14
500.00	-.93503078E-15	.21113083E-15	.95857121E-15
1000.00	-.87128276E-15	.12622787E-15	.88037896E-15
2000.00	-.84682449E-15	.69719920E-16	.84968969E-15
5000.00	-.83646374E-15	.29522187E-16	.83698455E-15
10000.00	-.83471785E-15	.14863522E-16	.83485017E-15

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	-.17142620E-14	.81797400E-17	.17142815E-14
.20	-.17108322E-14	.11508299E-16	.17108708E-14
.50	-.17040290E-14	.18008365E-16	.17041241E-14
1.00	-.16963652E-14	.25223002E-16	.16965526E-14
2.00	-.16850888E-14	.34742206E-16	.16854469E-14
5.00	-.16679057E-14	.50407457E-16	.16686672E-14
10.00	-.16562854E-14	.76942860E-16	.16580716E-14
20.00	-.16331309E-14	.13309382E-15	.16385452E-14
50.00	-.15302083E-14	.25723033E-15	.15516780E-14
100.00	-.13596019E-14	.33385116E-15	.13999906E-14
200.00	-.11545278E-14	.32560603E-15	.11995639E-14
500.00	-.96314597E-15	.21471288E-15	.98678861E-15
1000.00	-.89874573E-15	.12844150E-15	.90787724E-15
2000.00	-.87385480E-15	.70688870E-16	.87670925E-15
5000.00	-.86370871E-15	.29819283E-16	.86422330E-15
10000.00	-.86196951E-15	.15062732E-16	.86210110E-15

H(X) H.M.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

N(0,0)= .98058067E-05 N(2,0)= .17769398E-14 N(1,1)= .18857319E-10

T	REAL HX	IMAG. HX	ABS. HX
.10	-.18221235E-14	.90914397E-17	.18221461E-14
.20	-.18183084E-14	.12786681E-16	.18183533E-14
.50	-.18107415E-14	.19995347E-16	.18108518E-14
1.00	-.18022176E-14	.27984649E-16	.18024348E-14
2.00	-.17896831E-14	.38501675E-16	.17900971E-14
5.00	-.17705796E-14	.55797444E-16	.17714585E-14
10.00	-.17573957E-14	.85105765E-16	.17594551E-14
20.00	-.17306950E-14	.14650930E-15	.17368851E-14
50.00	-.16154038E-14	.27814857E-15	.16391754E-14
100.00	-.14314146E-14	.35460326E-15	.14746834E-14
200.00	-.12161647E-14	.34088721E-15	.12630362E-14
500.00	-.10193763E-14	.22187697E-15	.10432436E-14
1000.00	-.95367169E-15	.13286874E-15	.96288306E-15
2000.00	-.92791545E-15	.72626751E-16	.93075330E-15
5000.00	-.91819868E-15	.30413474E-16	.91870223E-15
10000.00	-.91647282E-15	.15461151E-16	.91660322E-15

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	-.18760544E-14	.95472900E-17	.18760786E-14
.20	-.18720466E-14	.13425872E-16	.18720947E-14
.50	-.18640979E-14	.20988841E-16	.18642160E-14
1.00	-.18551440E-14	.29365474E-16	.18553764E-14
2.00	-.18419804E-14	.40381409E-16	.18424229E-14
5.00	-.18219167E-14	.58492440E-16	.18228553E-14
10.00	-.18079510E-14	.89187220E-16	.18101494E-14
20.00	-.17794770E-14	.15321705E-15	.17860609E-14
50.00	-.16580017E-14	.28860770E-15	.16829331E-14
100.00	-.14673211E-14	.36497931E-15	.15120321E-14
200.00	-.12469833E-14	.34852781E-15	.12947737E-14
500.00	-.10474915E-14	.22545902E-15	.10714803E-14
1000.00	-.98113468E-15	.13508236E-15	.99039007E-15
2000.00	-.95494579E-15	.73595695E-16	.95777752E-15
5000.00	-.94544368E-15	.30710570E-16	.94594232E-15
10000.00	-.94372450E-15	.15660361E-16	.94385442E-15

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,0)= .31622777E-05 N(2,0)=-.22135945E-16 N(1,1)= .94868334E-11

T	REAL HX	IMAG. HX	ABS. HX
.10	.10739930E-15	-.11825134E-18	.10739936E-15
.20	.10735036E-15	-.16729158E-18	.10735048E-15
.50	.10725323E-15	-.26466890E-18	.10725355E-15
1.00	.10714382E-15	-.37533427E-18	.10714447E-15
2.00	.10698182E-15	-.52672052E-18	.10698311E-15
5.00	.10673451E-15	-.78243673E-18	.10673737E-15
10.00	.10661076E-15	-.11987288E-17	.10661749E-15
20.00	.10650308E-15	-.21105901E-17	.10652398E-15
50.00	.10641477E-15	-.48548740E-17	.10652545E-15
100.00	.10664551E-15	-.10391922E-16	.10715062E-15
200.00	.10102522E-15	-.23775419E-16	.10378518E-15
500.00	.71992288E-16	-.30396629E-16	.78146301E-16
1000.00	.57104469E-16	-.18951409E-16	.60167069E-16
2000.00	.53243413E-16	-.89516400E-17	.53990673E-16
5000.00	.53220766E-16	-.29666563E-17	.53303385E-16
10000.00	.53517073E-16	-.13127808E-17	.53533171E-16

H(X) H.M.D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(0,0)= .31622777E-05 N(2,0)=-.22135945E-16 N(1,1)= .94868334E-11

T	REAL HX	IMAG. HX	ABS. HX
.10	.64746526E-16	-.80234338E-19	.64746575E-16
.20	.64713315E-16	-.11350391E-18	.64713413E-16
.50	.64647406E-16	-.17955820E-18	.64647655E-16
1.00	.64573164E-16	-.25461360E-18	.64573665E-16
2.00	.64463234E-16	-.35726150E-18	.64464223E-16
5.00	.64295407E-16	-.53059365E-18	.64297596E-16
10.00	.64211269E-16	-.81277373E-18	.64216413E-16
20.00	.64137579E-16	-.14306118E-17	.64153531E-16
50.00	.64079688E-16	-.32927859E-17	.64164233E-16
100.00	.64213331E-16	-.71014449E-17	.64604817E-16
200.00	.60018865E-16	-.16160934E-16	.62156575E-16
500.00	.40224611E-16	-.19087118E-16	.44523446E-16
1000.00	.31684181E-16	-.10429047E-16	.33356443E-16
2000.00	.30642120E-16	-.39645404E-17	.30897525E-16
5000.00	.31651471E-16	-.84695370E-18	.31662799E-16
10000.00	.32113963E-16	-.24105660E-18	.32114867E-16

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	-.20559016E-16	-.42003410E-20	.20559016E-16
.20	-.20560764E-16	-.59285960E-20	.20560764E-16
.50	-.20564240E-16	-.93368220E-20	.20564242E-16
1.00	-.20568146E-16	-.13172312E-19	.20568150E-16
2.00	-.20573923E-16	-.18343513E-19	.20573931E-16
5.00	-.20582782E-16	-.26907580E-19	.20582799E-16
10.00	-.20587700E-16	-.40863640E-19	.20587740E-16
20.00	-.20593416E-16	-.70655560E-19	.20593537E-16
50.00	-.20590477E-16	-.16861037E-18	.20591167E-16
100.00	-.20651029E-16	-.52049050E-18	.20657587E-16
200.00	-.21993837E-16	-.93196810E-18	.22013573E-16
500.00	-.23310730E-16	.35319000E-17	.23576777E-16
1000.00	-.19156384E-16	.66156754E-17	.20266578E-16
2000.00	-.14560455E-16	.60096564E-17	.15751914E-16
5000.00	-.11487108E-16	.33924503E-17	.11977577E-16
10000.00	-.10692248E-16	.19023911E-17	.10860168E-16

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	-.63211800E-16	.33816670E-19	.63211809E-16
.20	-.63197816E-16	.47859080E-19	.63197833E-16
.50	-.63170075E-16	.75773893E-19	.63170120E-16
1.00	-.63138814E-16	.10754837E-18	.63138904E-16
2.00	-.63092515E-16	.15111553E-18	.63092695E-16
5.00	-.63021889E-16	.22493554E-18	.63022289E-16
10.00	-.62987197E-16	.34509153E-18	.62988141E-16
20.00	-.62958926E-16	.60932280E-18	.62961874E-16
50.00	-.62925573E-16	.13934779E-17	.62940999E-16
100.00	-.63083222E-16	.27699877E-17	.63144007E-16
200.00	-.63000200E-16	.66825176E-17	.63353620E-16
500.00	-.55078410E-16	.14841412E-16	.57042954E-16
1000.00	-.44576675E-16	.15138039E-16	.47076960E-16
2000.00	-.37161750E-16	.10996756E-16	.38754668E-16
5000.00	-.33056406E-16	.55121530E-17	.33512830E-16
10000.00	-.32095361E-16	.29741154E-17	.32232863E-16

C H(X) H. M. D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(0,0)= .19611613E-05 N(2,0)=-.66725903E-17 N(1,1)= .37714640E-11

T	REAL HX	IMAG. HX	ABS. HX
.10	.28430905E-16	-.12339112E-19	.28430907E-16
.20	.28425801E-16	-.17454172E-19	.28425806E-16
.50	.28415670E-16	-.27607400E-19	.28415683E-16
1.00	.28404249E-16	-.39141363E-19	.28404275E-16
2.00	.28387357E-16	-.54911900E-19	.28387410E-16
5.00	.28361574E-16	-.81656063E-19	.28361691E-16
10.00	.28348357E-16	-.12506785E-18	.28348632E-16
20.00	.28336752E-16	-.21921491E-18	.28337599E-16
50.00	.28317761E-16	-.49756925E-18	.28322131E-16
100.00	.28354614E-16	-.90099207E-18	.28368925E-16
200.00	.28936092E-16	-.20686225E-17	.29009939E-16
500.00	.26411193E-16	-.78918990E-17	.27565071E-16
1000.00	.19468357E-16	-.86253769E-17	.21293521E-16
2000.00	.15269006E-16	-.53593415E-17	.16182245E-16
5000.00	.14082156E-16	-.19973738E-17	.14223101E-16
10000.00	.14089557E-16	-.88766730E-18	.14117491E-16

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	.17552523E-16	-.84795223E-20	.17552524E-16
.20	.17549016E-16	-.11993524E-19	.17549019E-16
.50	.17542051E-16	-.18966851E-19	.17542060E-16
1.00	.17534202E-16	-.26885384E-19	.17534222E-16
2.00	.17522593E-16	-.37706831E-19	.17522633E-16
5.00	.17504871E-16	-.56053043E-19	.17504960E-16
10.00	.17495730E-16	-.85824538E-19	.17495940E-16
20.00	.17487592E-16	-.15028108E-18	.17488237E-16
50.00	.17474153E-16	-.34041319E-18	.17477468E-16
100.00	.17501181E-16	-.61470503E-18	.17511973E-16
200.00	.17908618E-16	-.14340429E-17	.17965941E-16
500.00	.15995331E-16	-.53990857E-17	.16881964E-16
1000.00	.11257852E-16	-.55309369E-17	.12543145E-16
2000.00	.87798520E-17	-.30784153E-17	.93038938E-17
5000.00	.84301092E-17	-.91847890E-18	.84799966E-17
10000.00	.85928479E-17	-.32926496E-18	.85991540E-17

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HX	IMAG. HX	ABS. HX
.10	-.42042366E-17	-.76034280E-21	.42042365E-17
.20	-.42045515E-17	-.10722287E-20	.42045515E-17
.50	-.42051798E-17	-.16857551E-20	.42051800E-17
1.00	-.42058884E-17	-.23734312E-20	.42058889E-17
2.00	-.42069306E-17	-.32967010E-20	.42069317E-17
5.00	-.42085303E-17	-.48470130E-20	.42085329E-17
10.00	-.42095166E-17	-.73379310E-20	.42095228E-17
20.00	-.42107233E-17	-.12413440E-19	.42107416E-17
50.00	-.42130568E-17	-.26101151E-19	.42131376E-17
100.00	-.42056804E-17	-.42131070E-19	.42058914E-17
200.00	-.41463226E-17	-.16488385E-18	.41495996E-17
500.00	-.48363889E-17	-.41346020E-18	.48540299E-17
1000.00	-.51631559E-17	.65794180E-18	.52049078E-17
2000.00	-.41984526E-17	.14834360E-17	.44528177E-17
5000.00	-.28739835E-17	.12393105E-17	.31298037E-17
10000.00	-.24005695E-17	.78753941E-18	.25264505E-17

C H(X) H. M. D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES
N(0,0)= .19611613E-05 N(2,0)=-.66725903E-17 N(1,1)= .37714640E-11

T	REAL HX	IMAG. HX	ABS. HX
.10	-.15082620E-16	.30992482E-20	.15082620E-16
.20	-.15081338E-16	.43884206E-20	.15081338E-16
.50	-.15078799E-16	.69547958E-20	.15078800E-16
1.00	-.15075937E-16	.98825492E-20	.15075940E-16
2.00	-.15071696E-16	.13908370E-19	.15071702E-16
5.00	-.15065234E-16	.20756010E-19	.15065248E-16
10.00	-.15062144E-16	.31905386E-19	.15062177E-16
20.00	-.15059884E-16	.56520404E-19	.15059990E-16
50.00	-.15056665E-16	.13105492E-18	.15057235E-16
100.00	-.15059114E-16	.24415602E-18	.15061092E-16
200.00	-.15173797E-16	.46969588E-18	.15181064E-16
500.00	-.15252252E-16	.20793534E-17	.15393339E-16
1000.00	-.13373662E-16	.37523822E-17	.13890111E-16
2000.00	-.10687607E-16	.37643624E-17	.11331167E-16
5000.00	-.85260317E-17	.23182056E-17	.88355698E-17
10000.00	-.78972799E-17	.13459417E-17	.80111540E-17

H(Y) OF A H.M.D.=0 AT THETA=0 AND 90
DEGREES FOR ALL R

C H(Y) H. M. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(2,0)= .17769398E-14 N(1,1)= .18857319E-10

T	REAL HY	IMAG. HY	ABS. HY
.10	.93410885E-16	-.78955580E-18	.93414221E-16
.20	.93077210E-16	-.11071121E-17	.93083793E-16
.50	.92415825E-16	-.17207795E-17	.92431843E-16
1.00	.91671000E-16	-.23916586E-17	.91702192E-16
2.00	.90581410E-16	-.32557966E-17	.90639902E-16
5.00	.88918295E-16	-.46678683E-17	.89040732E-16
10.00	.87564220E-16	-.70692875E-17	.87849117E-16
20.00	.84492945E-16	-.11618151E-16	.85287978E-16
50.00	.73781600E-16	-.18115736E-16	.75973049E-16
100.00	.62191755E-16	-.17971842E-16	.64736400E-16
200.00	.53379175E-16	-.13233894E-16	.54995201E-16
500.00	.48696986E-16	-.62042925E-17	.49090626E-16
1000.00	.47567303E-16	-.38341067E-17	.47721573E-16
2000.00	.46817919E-16	-.16782620E-17	.46847988E-16
5000.00	.47189725E-16	-.51458495E-18	.47192529E-16
10000.00	.47201291E-16	-.34504141E-18	.47202551E-16

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(2,0)=-.22135945E-16 N(1,1)= .94868334E-11

T	REAL HY	IMAG. HY	ABS. HY
.10	.73876775E-16	-.65847380E-19	.73876804E-16
.20	.73849525E-16	-.93162970E-19	.73849582E-16
.50	.73795455E-16	-.14741605E-18	.73795602E-16
1.00	.73734545E-16	-.20909432E-18	.73734841E-16
2.00	.73644345E-16	-.29351162E-18	.73644929E-16
5.00	.73506675E-16	-.43620496E-18	.73507968E-16
10.00	.73438070E-16	-.66849380E-18	.73441111E-16
20.00	.73379200E-16	-.11777568E-17	.73388651E-16
50.00	.73326525E-16	-.27056158E-17	.73376424E-16
100.00	.73494700E-16	-.56992745E-17	.73715348E-16
200.00	.71025085E-16	-.13188674E-16	.72239212E-16
500.00	.55023230E-16	-.19588647E-16	.58406085E-16
1000.00	.44029226E-16	-.14761164E-16	.46437749E-16
2000.00	.39146585E-16	-.86379090E-17	.40088258E-16
5000.00	.37359112E-16	-.36714325E-17	.37539080E-16
10000.00	.37071272E-16	-.18562804E-17	.37117716E-16

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(2,0)=-.66725903E-17 N(1,1)= .37714640E-11

T	REAL HY	IMAG. HY	ABS. HY
.10	.18841909E-16	-.66850065E-20	.18841909E-16
.20	.18839144E-16	-.94581205E-20	.18839146E-16
.50	.18833658E-16	-.14965870E-19	.18833663E-16
1.00	.18827473E-16	-.21227977E-19	.18827484E-16
2.00	.18818322E-16	-.29800051E-19	.18818345E-16
5.00	.18804360E-16	-.44345728E-19	.18804412E-16
10.00	.18797298E-16	-.67971405E-19	.18797420E-16
20.00	.18791295E-16	-.11939689E-18	.18791674E-16
50.00	.18781678E-16	-.27220225E-18	.18783650E-16
100.00	.18798696E-16	-.49586364E-18	.18805234E-16
200.00	.19100142E-16	-.10991241E-17	.19131740E-16
500.00	.18040801E-16	-.43176790E-17	.18550278E-16
1000.00	.14221011E-16	-.53597270E-17	.15197493E-16
2000.00	.11239543E-16	-.39506797E-17	.11913656E-16
5000.00	.97896330E-17	-.18687007E-17	.99663913E-17
10000.00	.95205800E-17	-.96718115E-18	.95695811E-17

THE H(Z) OF A H.M.D.
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(2,1)= .54396117E-15

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	-.73694900E-17	-.72471521E-17	.10335888E-16
.20	-.10421190E-16	-.10177520E-16	.14566506E-16
.50	-.16472800E-16	-.15867637E-16	.22872145E-16
1.00	-.23288170E-16	-.22131818E-16	.32127187E-16
2.00	-.33287000E-16	-.30290959E-16	.45006295E-16
5.00	-.48530100E-16	-.43661379E-16	.65280062E-16
10.00	-.59977070E-16	-.66418318E-16	.89491015E-16
20.00	-.84943890E-16	-.11206009E-15	.14061624E-15
50.00	-.18277840E-15	-.19357867E-15	.26623419E-15
100.00	-.31125698E-15	-.21676833E-15	.37930121E-15
200.00	-.43079138E-15	-.17932948E-15	.46662647E-15
500.00	-.51390505E-15	-.98242985E-16	.52321131E-15
1000.00	-.53477632E-15	-.53749339E-16	.53747065E-15
2000.00	-.54142476E-15	-.27828650E-16	.54213946E-15
5000.00	-.54353020E-15	-.11275332E-16	.54364713E-15
10000.00	-.54384860E-15	-.56529726E-17	.54387797E-15

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(2,1)= .54396117E-15

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	-.63821655E-17	-.62762178E-17	.89511421E-17
.20	-.90250152E-17	-.88139908E-17	.12614964E-16
.50	-.14265863E-16	-.13741777E-16	.19807859E-16
1.00	-.20168147E-16	-.19166717E-16	.27822961E-16
2.00	-.28827387E-16	-.26232740E-16	.38976592E-16
5.00	-.42028299E-16	-.37811863E-16	.56534192E-16
10.00	-.51941666E-16	-.57519950E-16	.77501492E-16
20.00	-.73563566E-16	-.97046884E-16	.12177723E-15
50.00	-.15829074E-15	-.16764405E-15	.23056557E-15
100.00	-.26955645E-15	-.18772688E-15	.32848448E-15
200.00	-.37307628E-15	-.15530388E-15	.40411038E-15
500.00	-.44505483E-15	-.85080920E-16	.45311429E-15
1000.00	-.46312988E-15	-.46548293E-16	.46546324E-15
2000.00	-.46888759E-15	-.24100318E-16	.46950653E-15
5000.00	-.47071096E-15	-.97647239E-17	.47081222E-15
10000.00	-.47098670E-15	-.48956179E-17	.47101213E-15

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES
N(2,1)= .54396117E-15

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	-.36847454E-17	-.36235764E-17	.51679449E-17
.20	-.52105955E-17	-.50887605E-17	.72832539E-17
.50	-.82364008E-17	-.79338193E-17	.11436073E-16
1.00	-.11644086E-16	-.11065910E-16	.16063595E-16
2.00	-.16643502E-16	-.15145481E-16	.22503149E-16
5.00	-.24265052E-16	-.21830692E-16	.32640033E-16
10.00	-.29988538E-16	-.33209162E-16	.44745511E-16
20.00	-.42471949E-16	-.56030051E-16	.70308129E-16
50.00	-.91389209E-16	-.96789345E-16	.13311710E-15
100.00	-.15562851E-15	-.10838418E-15	.18965063E-15
200.00	-.21539571E-15	-.89664749E-16	.23331326E-15
500.00	-.25695255E-15	-.49121497E-16	.26160568E-15
1000.00	-.26738819E-15	-.26874672E-16	.26873535E-15
2000.00	-.27071241E-15	-.13914326E-16	.27106976E-15
5000.00	-.27176513E-15	-.56376666E-17	.27182359E-15
10000.00	-.27192433E-15	-.28264866E-17	.27193901E-15

THE H(Z) OF A H.M.D.
R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(2,1)= .28460501E-16

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.50614000E-19	.50221658E-19	.71302117E-19
.20	.71596000E-19	.70781772E-19	.10067793E-18
.50	.11320900E-18	.11114341E-18	.15864783E-18
1.00	.16009000E-18	.15627925E-18	.22372306E-18
2.00	.22931700E-18	.21653945E-18	.31539755E-18
5.00	.33515900E-18	.31561668E-18	.46037532E-18
10.00	.39799400E-18	.47981124E-18	.62339237E-18
20.00	.48845900E-18	.84266120E-18	.97399696E-18
50.00	.92077800E-18	.20451909E-17	.22429083E-17
100.00	.31964910E-17	.40478249E-17	.51577554E-17
200.00	.10819207E-16	.13511266E-17	.10903246E-16
500.00	.64425870E-17	-.17768060E-16	.18900023E-16
1000.00	-.10244389E-16	-.21193152E-16	.23539269E-16
2000.00	-.21602475E-16	-.15166675E-16	.26394979E-16
5000.00	-.27008671E-16	-.71724933E-17	.27944820E-16
10000.00	-.28052406E-16	-.37347085E-17	.28299920E-16

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.43833010E-19	.43493231E-19	.61749444E-19
.20	.62003955E-19	.61298812E-19	.87189648E-19
.50	.98041870E-19	.96253016E-19	.13739305E-18
1.00	.13864201E-18	.13534180E-18	.19374986E-18
2.00	.19859435E-18	.18752866E-18	.27314229E-18
5.00	.29025621E-18	.27333206E-18	.39869672E-18
10.00	.34467291E-18	.41552872E-18	.53987362E-18
20.00	.42301790E-18	.72976600E-18	.84350610E-18
50.00	.79741714E-18	.17711873E-17	.19424156E-17
100.00	.27682424E-17	.35055192E-17	.44667472E-17
200.00	.93697081E-17	.11701100E-17	.94424883E-17
500.00	.55794440E-17	-.15387591E-16	.16367899E-16
1000.00	-.88719011E-17	-.18353808E-16	.20385604E-16
2000.00	-.18708292E-16	-.13134726E-16	.22858723E-16
5000.00	-.23390195E-16	-.62115614E-17	.24200923E-16
10000.00	-.24294096E-16	-.32343524E-17	.24508450E-16

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.25307003E-19	.25110832E-19	.35651061E-19
.20	.35798004E-19	.35390890E-19	.50338972E-19
.50	.56604506E-19	.55571711E-19	.79323925E-19
1.00	.80045008E-19	.78139633E-19	.11186154E-18
2.00	.11465851E-18	.10826974E-18	.15769879E-18
5.00	.16757952E-18	.15780836E-18	.23018769E-18
10.00	.19899702E-18	.23990564E-18	.31169621E-18
20.00	.24422952E-18	.42133064E-18	.48699852E-18
50.00	.46038905E-18	.10225956E-17	.11214543E-17
100.00	.15982457E-17	.20239127E-17	.25788780E-17
200.00	.54096040E-17	.67556337E-18	.54516236E-17
500.00	.32212938E-17	-.88840309E-17	.94500126E-17
1000.00	-.51221950E-17	-.10596577E-16	.11769635E-16
2000.00	-.10801239E-16	-.75833383E-17	.13197491E-16
5000.00	-.13504337E-16	-.35862470E-17	.13972411E-16
10000.00	-.14026204E-16	-.18673544E-17	.14149961E-16

THE H(Z) OF A H.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(2,1)= .43516893E-17

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.35631000E-20	.12885695E-19	.13369249E-19
.20	.89166000E-20	.18194905E-19	.20262288E-19
.50	.19543900E-19	.28678625E-19	.34704862E-19
1.00	.31512100E-19	.40498985E-19	.51314522E-19
2.00	.49199200E-19	.56483604E-19	.74906333E-19
5.00	.76239200E-19	.83228622E-19	.11286903E-18
10.00	.91230900E-19	.12696343E-18	.15634190E-18
20.00	.10898250E-18	.22211580E-18	.24741183E-18
50.00	.16460480E-18	.50018003E-18	.52656889E-18
100.00	.25103180E-18	.96950058E-18	.10014730E-17
200.00	.90974160E-18	.21960712E-17	.23770482E-17
500.00	.51158500E-17	.98398872E-18	.52096212E-17
1000.00	.41294584E-17	-.36249968E-17	.54948183E-17
2000.00	.47326900E-19	-.48286122E-17	.48288440E-17
5000.00	-.31886522E-17	-.29920078E-17	.43725979E-17
10000.00	-.39933827E-17	-.16739434E-17	.43300336E-17

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.30857351E-20	.11159339E-19	.11578109E-19
.20	.77220021E-20	.15757250E-19	.17547656E-19
.50	.16925514E-19	.24836418E-19	.30055293E-19
1.00	.27290279E-19	.35073150E-19	.44439680E-19
2.00	.42607757E-19	.48916236E-19	.64870787E-19
5.00	.66025084E-19	.72078101E-19	.97747451E-19
10.00	.79008277E-19	.10995356E-18	.13539605E-18
20.00	.94381613E-19	.19235792E-18	.21426492E-18
50.00	.14255194E-18	.43316861E-18	.45602202E-18
100.00	.21739992E-18	.83961213E-18	.86730112E-18
200.00	.78785933E-18	.19018534E-17	.20585841E-17
500.00	.44304560E-17	.85215922E-18	.45116643E-17
1000.00	.35762159E-17	-.31393393E-17	.47586522E-17
2000.00	.40986298E-19	-.41817008E-17	.41819016E-17
5000.00	-.27614538E-17	-.25911548E-17	.37867809E-17
10000.00	-.34583709E-17	-.14496775E-17	.37499190E-17

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.17815502E-20	.64428481E-20	.66846251E-20
.20	.44583004E-20	.90974534E-20	.10131145E-19
.50	.97719510E-20	.14339314E-19	.17352433E-19
1.00	.15756052E-19	.20249495E-19	.25657264E-19
2.00	.24599602E-19	.28241805E-19	.37453169E-19
5.00	.38119604E-19	.41614315E-19	.56434523E-19
10.00	.45615455E-19	.63481721E-19	.78170957E-19
20.00	.54491255E-19	.11105791E-18	.12370592E-18
50.00	.82302408E-19	.25009004E-18	.26328447E-18
100.00	.12551591E-18	.48475034E-18	.50073658E-18
200.00	.45487085E-18	.10980357E-17	.11885242E-17
500.00	.25579253E-17	.49199441E-18	.26048109E-17
1000.00	.20647294E-17	-.18124986E-17	.27474094E-17
2000.00	.23663452E-19	-.24143063E-17	.24144222E-17
5000.00	-.15943263E-17	-.14960040E-17	.21862992E-17
10000.00	-.19966915E-17	-.83697178E-18	.21650169E-17

E(RHO) OF A V.E.D.
R = .20 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL E	IMAG. E	ABS. E
.10	.29480962E-21	.29483014E-21	.41693826E-21
.20	.10422733E-21	.10424183E-21	.14740995E-21
.50	.26364510E-22	.26371490E-22	.37289982E-22
1.00	.93189712E-23	.93438578E-23	.13196624E-22
2.00	.33386284E-23	.32760040E-23	.46774610E-23
5.00	.78053322E-24	.77699858E-24	.11013441E-23
10.00	.22458332E-24	.29658640E-24	.37202306E-24
20.00	.61096424E-25	.13108972E-24	.14462810E-24
50.00	.10824655E-25	.49268754E-25	.50443861E-25
100.00	.29414514E-26	.24131504E-25	.24310113E-25
200.00	.80020678E-27	.11932384E-25	.11959185E-25
500.00	.14284854E-27	.47372624E-26	.47394155E-26
1000.00	.37816472E-28	.23624842E-26	.23627868E-26
2000.00	.97888502E-29	.11800433E-26	.11800838E-26
5000.00	.16314869E-29	.47180408E-27	.47180689E-27
10000.00	.42051502E-30	.23586946E-27	.23586983E-27

E(RHO) OF A V.E.D.
R = 3.00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL E	IMAG. E	ABS. E
.10	.14831952E-21	.14831938E-21	.20975537E-21
.20	.52438890E-22	.52438796E-22	.74159722E-22
.50	.13265921E-22	.13264757E-22	.18760022E-22
1.00	.46899270E-23	.46991172E-23	.66390599E-23
2.00	.16806825E-23	.16467024E-23	.23529391E-23
5.00	.39291754E-24	.39089412E-24	.55424038E-24
10.00	.11404737E-24	.14985651E-24	.18831828E-24
20.00	.32401442E-25	.66265194E-25	.73762655E-25
50.00	.71178328E-26	.24414668E-25	.25431074E-25
100.00	.27357174E-26	.11411204E-25	.11734552E-25
200.00	.11237930E-26	.52345996E-26	.53538717E-26
500.00	.31431148E-27	.18736737E-26	.18998538E-26
1000.00	.10620242E-27	.88377384E-27	.89013209E-27
2000.00	.32660906E-28	.42742120E-27	.42866724E-27
5000.00	.61680350E-29	.16778474E-27	.16789807E-27
10000.00	.16539168E-29	.83480540E-28	.83496922E-28

E(RHO) OF A V.E.D.
R = 5.00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	REAL E	IMAG. E	ABS. E
.10	.58962868E-22	.58962830E-22	.83386060E-22
.20	.20846528E-22	.20846502E-22	.29481424E-22
.50	.52737232E-23	.52732726E-23	.74578522E-23
1.00	.18644284E-23	.18680885E-23	.26392892E-23
2.00	.66813562E-24	.65463218E-24	.93538681E-24
5.00	.15620084E-24	.15539587E-24	.22033287E-24
10.00	.45337966E-25	.59570356E-25	.74860927E-25
20.00	.12874105E-25	.26331884E-25	.29310590E-25
50.00	.27865526E-26	.97293006E-26	.10120482E-25
100.00	.10954593E-26	.46205156E-26	.47485992E-26
200.00	.53453396E-27	.21340878E-26	.22000129E-26
500.00	.20578702E-27	.71677644E-27	.74573235E-27
1000.00	.83808416E-28	.30991346E-27	.32104547E-27
2000.00	.29204152E-28	.13874467E-27	.14178492E-27
5000.00	.60705020E-29	.51400096E-28	.51757326E-28

H(PHI) OF A V.E.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .18857319E-10

T	REAL HT	IMAG. HT	ABS. HT
.10	.00000000E-99	.20981153E-19	.20981152E-19
.20	.00000000E-99	.10490576E-19	.10490575E-19
.50	.00000000E-99	.41962302E-20	.41962302E-20
1.00	.00000000E-99	.20981153E-20	.20981152E-20
2.00	.00000000E-99	.10490576E-20	.10490575E-20
5.00	.00000000E-99	.41962302E-21	.41962302E-21
10.00	.00000000E-99	.20981153E-21	.20981152E-21
20.00	.00000000E-99	.10490576E-21	.10490575E-21
50.00	.00000000E-99	.41962302E-22	.41962302E-22
100.00	.00000000E-99	.20981153E-22	.20981152E-22
200.00	.00000000E-99	.10490576E-22	.10490575E-22
500.00	.00000000E-99	.41962302E-23	.41962302E-23
1000.00	.00000000E-99	.20981153E-23	.20981152E-23
2000.00	.00000000E-99	.10490576E-23	.10490575E-23
5000.00	.00000000E-99	.41962302E-24	.41962302E-24
10000.00	.00000000E-99	.20981153E-24	.20981152E-24

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .94868334E-11

T	REAL HT	IMAG. HT	ABS. HT
.10	.00000000E-99	.10555302E-19	.10555301E-19
.20	.00000000E-99	.52776508E-20	.52776508E-20
.50	.00000000E-99	.21110603E-20	.21110603E-20
1.00	.00000000E-99	.10555302E-20	.10555301E-20
2.00	.00000000E-99	.52776508E-21	.52776508E-21
5.00	.00000000E-99	.21110603E-21	.21110603E-21
10.00	.00000000E-99	.10555302E-21	.10555301E-21
20.00	.00000000E-99	.52776508E-22	.52776508E-22
50.00	.00000000E-99	.21110603E-22	.21110603E-22
100.00	.00000000E-99	.10555302E-22	.10555301E-22
200.00	.00000000E-99	.52776508E-23	.52776508E-23
500.00	.00000000E-99	.21110603E-23	.21110603E-23
1000.00	.00000000E-99	.10555302E-23	.10555301E-23
2000.00	.00000000E-99	.52776508E-24	.52776508E-24
5000.00	.00000000E-99	.21110603E-24	.21110603E-24
10000.00	.00000000E-99	.10555302E-24	.10555301E-24

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,1)= .37714640E-11

T	REAL HT	IMAG. HT	ABS. HT
10000.00	.16929989E-29	.25119940E-28	.25176926E-28
.10	.00000000E-99	.41962308E-20	.41962308E-20
.20	.00000000E-99	.20981153E-20	.20981152E-20
.50	.00000000E-99	.83924608E-21	.83924607E-21
1.00	.00000000E-99	.41962308E-21	.41962308E-21
2.00	.00000000E-99	.20981153E-21	.20981152E-21
5.00	.00000000E-99	.83924608E-22	.83924607E-22
10.00	.00000000E-99	.41962308E-22	.41962308E-22
20.00	.00000000E-99	.20981153E-22	.20981152E-22
50.00	.00000000E-99	.83924608E-23	.83924607E-23
100.00	.00000000E-99	.41962308E-23	.41962308E-23
200.00	.00000000E-99	.20981153E-23	.20981152E-23
500.00	.00000000E-99	.83924608E-24	.83924607E-24
1000.00	.00000000E-99	.41962308E-24	.41962308E-24
2000.00	.00000000E-99	.20981153E-24	.20981152E-24
5000.00	.00000000E-99	.83924608E-25	.83924607E-25
10000.00	.00000000E-99	.41962308E-25	.41962308E-25

C E(X) H. E. D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(0,0)= .10000000E-04

T	REAL EX	IMAG. EX	ABS. EX
.10	-.10828014E-18	.15523165E-20	.10829126E-18
.20	-.26908152E-19	.54720826E-21	.26913715E-19
.50	-.42539210E-20	.13761060E-21	.42561461E-20
1.00	-.10490063E-20	.48427875E-22	.10501235E-20
2.00	-.25691256E-21	.16803457E-22	.25746149E-21
5.00	-.39803113E-22	.39360879E-23	.39997256E-22
10.00	-.97562290E-23	.15037925E-23	.98714434E-23
20.00	-.23617141E-23	.65960546E-24	.24520955E-23
50.00	-.32214507E-24	.22765979E-24	.39446980E-24
100.00	-.50535786E-25	.91498856E-25	.10452705E-24
200.00	.11298177E-26	.30989106E-25	.31009694E-25
500.00	.41324912E-26	.55690705E-26	.69348417E-26
1000.00	.17379259E-26	.12155487E-26	.21208359E-26
2000.00	.55282784E-27	.24435602E-27	.60442408E-27
5000.00	.10836833E-27	.30701877E-28	.11263347E-27
10000.00	.30327545E-28	.56310762E-29	.30845891E-28

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,0)= .98058067E-05 N(-1,1)= .99019500E-01

T	REAL EX	IMAG. EX	ABS. EX
.10	-.10518018E-18	.14642309E-20	.10519036E-18
.20	-.26142397E-19	.51624476E-21	.26147493E-19
.50	-.41343386E-20	.12986783E-21	.41363777E-20
1.00	-.10199365E-20	.45720482E-22	.10209607E-20
2.00	-.24994879E-21	.15873160E-22	.25045230E-21
5.00	-.38762975E-22	.37205902E-23	.38941120E-22
10.00	-.95091886E-23	.14216744E-23	.96148752E-23
20.00	-.23066193E-23	.62441117E-24	.23896405E-23
50.00	-.31782387E-24	.21713121E-24	.38491293E-24
100.00	-.51204192E-25	.88200465E-25	.10198622E-24
200.00	.49231216E-27	.30226371E-25	.30230379E-25
500.00	.39247769E-26	.54535285E-26	.67189915E-26
1000.00	.16755120E-26	.12362269E-26	.20822097E-26
2000.00	.55736063E-27	.24600471E-27	.60923655E-27
5000.00	.10617109E-27	.25332660E-28	.10915146E-27
10000.00	.28469198E-28	.47604119E-29	.28864454E-28

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.10570818E-18	.14642309E-20	.10571831E-18
.20	-.26274397E-19	.51624476E-21	.26279468E-19
.50	-.41554586E-20	.12986783E-21	.41574873E-20
1.00	-.10252165E-20	.45720482E-22	.10262354E-20
2.00	-.25126879E-21	.15873160E-22	.25176966E-21
5.00	-.38974176E-22	.37205902E-23	.39151361E-22
10.00	-.95619887E-23	.14216744E-23	.96670981E-23
20.00	-.23198193E-23	.62441117E-24	.24023844E-23
50.00	-.31993588E-24	.21713121E-24	.38665867E-24
100.00	-.51732193E-25	.88200465E-25	.10225233E-24
200.00	.36031208E-27	.30226371E-25	.30228518E-25
500.00	.39036568E-26	.54535285E-26	.67066764E-26
1000.00	.16702320E-26	.12362269E-26	.20779633E-26
2000.00	.55604063E-27	.24600471E-27	.60802918E-27
5000.00	.10595989E-27	.25332660E-28	.10894604E-27
10000.00	.28416398E-28	.47604119E-29	.28812379E-28

C E(X) H. E. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES
N(0,0)= .98058067E-05 N(-1,1)= .99019500E-01

T	REAL EX	IMAG. EX	ABS. EX
.10	-.10676427E-18	.14642309E-20	.10677430E-18
.20	-.26538421E-19	.51624476E-21	.26543441E-19
.50	-.41977025E-20	.12986783E-21	.41997108E-20
1.00	-.10357774E-20	.45720482E-22	.10367859E-20
2.00	-.25390903E-21	.15873160E-22	.25440470E-21
5.00	-.39396614E-22	.37205902E-23	.39571907E-22
10.00	-.96675984E-23	.14216744E-23	.97715718E-23
20.00	-.23462218E-23	.62441117E-24	.24278892E-23
50.00	-.32416026E-24	.21713121E-24	.39016128E-24
100.00	-.52788290E-25	.88200465E-25	.10279068E-24
200.00	.96287749E-28	.30226371E-25	.30226524E-25
500.00	.38614130E-26	.54535285E-26	.66821765E-26
1000.00	.16596710E-26	.12362269E-26	.20694841E-26
2000.00	.55340039E-27	.24600471E-27	.60561563E-27
5000.00	.10553745E-27	.25332660E-28	.10853522E-27
10000.00	.28310788E-28	.47604119E-29	.28708225E-28

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.10729232E-18	.14642309E-20	.10730230E-18
.20	-.26670433E-19	.51624476E-21	.26675428E-19
.50	-.42188245E-20	.12986783E-21	.42208227E-20
1.00	-.10410579E-20	.45720482E-22	.10420613E-20
2.00	-.25522915E-21	.15873160E-22	.25572226E-21
5.00	-.39607834E-22	.37205902E-23	.39782197E-22
10.00	-.97204033E-23	.14216744E-23	.98238178E-23
20.00	-.23594230E-23	.62441117E-24	.24406487E-23
50.00	-.32627246E-24	.21713121E-24	.39191795E-24
100.00	-.53316339E-25	.88200465E-25	.10306286E-24
200.00	-.35724415E-28	.30226371E-25	.30226391E-25
500.00	.38402910E-26	.54535285E-26	.66699931E-26
1000.00	.16543905E-26	.12362269E-26	.20652517E-26
2000.00	.55208027E-27	.24600471E-27	.60440957E-27
5000.00	.10532623E-27	.25332660E-28	.10832985E-27
10000.00	.28257984E-28	.47604119E-29	.28656154E-28

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(0,0)= .31622777E-05 N(-1,1)= .72075920E-00

T	REAL EX	IMAG. EX	ABS. EX
.10	-.16641227E-19	.49559914E-22	.16641300E-19
.20	-.41551889E-20	.17540103E-22	.41552258E-20
.50	-.66320572E-21	.44459071E-23	.66322061E-21
1.00	-.16534331E-21	.15786704E-23	.16535084E-21
2.00	-.41166272E-22	.55508133E-24	.41170014E-22
5.00	-.65452509E-23	.13240875E-24	.65465900E-23
10.00	-.16313085E-23	.50843805E-25	.16321006E-23
20.00	-.40687003E-24	.22486923E-25	.40749095E-24
50.00	-.64890145E-25	.82786903E-26	.65416111E-25
100.00	-.16381425E-25	.39454509E-26	.16849856E-25
200.00	-.43593210E-26	.21720354E-26	.48704637E-26
500.00	-.51738764E-27	.10915626E-26	.12079730E-26
1000.00	.64983749E-28	.43861556E-27	.44340330E-27
2000.00	.87715350E-28	.12515922E-27	.15283589E-27
5000.00	.27686818E-28	.17198369E-28	.32593614E-28
10000.00	.87141072E-29	.33355569E-29	.93306807E-29

C E(X) H. E. D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(0,0)= .31622777E-05 N(-1,1)= .72075920E-00

T	REAL EX	IMAG. EX	ABS. EX
.10	-.25663674E-19	.49559914E-22	.25663721E-19
.20	-.64108007E-20	.17540103E-22	.64108246E-20
.50	-.10241036E-20	.44459071E-23	.10241132E-20
1.00	-.25556779E-21	.15786704E-23	.25557266E-21
2.00	-.63722390E-22	.55508133E-24	.63724807E-22
5.00	-.10154230E-22	.13240875E-24	.10155093E-22
10.00	-.25335532E-23	.50843805E-25	.25340632E-23
20.00	-.63243121E-24	.22486923E-25	.63283086E-24
50.00	-.10097993E-24	.82786903E-26	.10131871E-24
100.00	-.25403873E-25	.39454509E-26	.25708429E-25
200.00	-.66149329E-26	.21720354E-26	.69624043E-26
500.00	-.87828550E-27	.10915626E-26	.14010332E-26
1000.00	-.25240724E-28	.43861556E-27	.43934121E-27
2000.00	.65159233E-28	.12515922E-27	.14110476E-27
5000.00	.24077839E-28	.17198369E-28	.29589292E-28
10000.00	.78118625E-29	.33355569E-29	.84941824E-29

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.43708599E-19	.49559914E-22	.43708626E-19
.20	-.10922032E-19	.17540103E-22	.10922045E-19
.50	-.17459005E-20	.44459071E-23	.17459061E-20
1.00	-.43601704E-21	.15786704E-23	.43601989E-21
2.00	-.10883470E-21	.55508133E-24	.10883611E-21
5.00	-.17372198E-22	.13240875E-24	.17372702E-22
10.00	-.43380457E-23	.50843805E-25	.43383435E-23
20.00	-.10835543E-23	.22486923E-25	.10837875E-23
50.00	-.17315962E-24	.82786903E-26	.17335740E-24
100.00	-.43448797E-25	.39454509E-26	.43627565E-25
200.00	-.11126163E-25	.21720354E-26	.11336191E-25
500.00	-.16000824E-26	.10915626E-26	.19369493E-26
1000.00	-.20568997E-27	.43861556E-27	.48445017E-27
2000.00	.20046923E-28	.12515922E-27	.12675452E-27
5000.00	.16859871E-28	.17198369E-28	.24084001E-28
10000.00	.60073703E-29	.33355569E-29	.68712763E-29

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.52731062E-19	.49559914E-22	.52731084E-19
.20	-.13177647E-19	.17540103E-22	.13177658E-19
.50	-.21067989E-20	.44459071E-23	.21068035E-20
1.00	-.52624166E-21	.15786704E-23	.52624402E-21
2.00	-.13139086E-21	.55508133E-24	.13139203E-21
5.00	-.20981183E-22	.13240875E-24	.20981600E-22
10.00	-.52402919E-23	.50843805E-25	.52405385E-23
20.00	-.13091159E-23	.22486923E-25	.13093089E-23
50.00	-.20924947E-24	.82786903E-26	.20941317E-24
100.00	-.52471260E-25	.39454509E-26	.52619384E-25
200.00	-.13381779E-25	.21720354E-26	.13556907E-25
500.00	-.19609809E-26	.10915626E-26	.22443161E-26
1000.00	-.29591460E-27	.43861556E-27	.52910212E-27
2000.00	-.25092329E-29	.12515922E-27	.12518436E-27
5000.00	.13250886E-28	.17198369E-28	.21711054E-28
10000.00	.51051237E-29	.33355569E-29	.60982151E-29

C E(X) OF A H. E. D.

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(0,0)= .19611613E-05 N(-1,1)= .81980390E-00

T	REAL EX	IMAG. EX	ABS. EX
.10	-.70522939E-20	.11827416E-22	.70523037E-20
.20	-.17618464E-20	.41870368E-23	.17618513E-20
.50	-.28150823E-21	.10618877E-23	.28151023E-21
1.00	-.70267838E-22	.37729419E-24	.70268850E-22
2.00	-.17526514E-22	.13277963E-24	.17527016E-22
5.00	-.27943860E-23	.31720467E-25	.27945660E-23
10.00	-.69741864E-24	.12194331E-25	.69752523E-24
20.00	-.17414342E-24	.54022262E-26	.17422719E-24
50.00	-.27821855E-25	.20078359E-26	.27894211E-25
100.00	-.69618268E-26	.95683297E-27	.70272726E-26
200.00	-.17981355E-26	.44013882E-27	.18512194E-26
500.00	-.36792346E-27	.25668751E-27	.44861580E-27
1000.00	-.65144867E-28	.17188740E-27	.18381820E-27
2000.00	.15927786E-28	.69586378E-28	.71385981E-28
5000.00	.12070925E-28	.12313370E-28	.17243152E-28
10000.00	.45411615E-29	.26542483E-29	.52599602E-29

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.14291273E-19	.11827416E-22	.14291277E-19
.20	-.35715910E-20	.41870368E-23	.35715933E-20
.50	-.57106734E-21	.10618877E-23	.57106832E-21
1.00	-.14265763E-21	.37729419E-24	.14265812E-21
2.00	-.35623960E-22	.13277963E-24	.35624206E-22
5.00	-.56899772E-23	.31720467E-25	.56900656E-23
10.00	-.14213165E-23	.12194331E-25	.14213688E-23
20.00	-.35511788E-24	.54022262E-26	.35515896E-24
50.00	-.56777766E-25	.20078359E-26	.56813256E-25
100.00	-.14200805E-25	.95683297E-27	.14233003E-25
200.00	-.36078801E-26	.44013882E-27	.36346280E-26
500.00	-.65748257E-27	.25668751E-27	.70581286E-27
1000.00	-.13753465E-27	.17188740E-27	.22013872E-27
2000.00	-.21696604E-29	.69586378E-28	.69620193E-28
5000.00	.91753342E-29	.12313370E-28	.15355970E-28
10000.00	.38172636E-29	.26542483E-29	.46493585E-29

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL EX	IMAG. EX	ABS. EX
.10	-.28769254E-19	.11827416E-22	.28769256E-19
.20	-.71910862E-20	.41870368E-23	.71910874E-20
.50	-.11501865E-20	.10618877E-23	.11501869E-20
1.00	-.28743744E-21	.37729419E-24	.28743768E-21
2.00	-.71818912E-22	.13277963E-24	.71819034E-22
5.00	-.11481169E-22	.31720467E-25	.11481212E-22
10.00	-.28691146E-23	.12194331E-25	.28691405E-23
20.00	-.71706739E-24	.54022262E-26	.71708773E-24
50.00	-.11468968E-24	.20078359E-26	.11470725E-24
100.00	-.28678787E-25	.95683297E-27	.28694744E-25
200.00	-.72273752E-26	.44013882E-27	.72407647E-26
500.00	-.12366017E-26	.25668751E-27	.12629616E-26
1000.00	-.28231447E-27	.17188740E-27	.33052493E-27
2000.00	-.38364612E-28	.69586378E-28	.79461358E-28
5000.00	.33841425E-29	.12313370E-28	.12769945E-28
10000.00	.23694655E-29	.26542483E-29	.35580050E-29

E(X) H.E.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES
N(0,0)= .19611613E-05 N(-1,1)= .81980390E-00

T	REAL EX	IMAG. EX	ABS. EX
.10	-.36008243E-19	.11827416E-22	.36008244E-19
.20	-.90008334E-20	.41870368E-23	.90008343E-20
.50	-.14397461E-20	.10618877E-23	.14397464E-20
1.00	-.35982733E-21	.37729419E-24	.35982752E-21
2.00	-.89916384E-22	.13277963E-24	.89916481E-22
5.00	-.14376764E-22	.31720467E-25	.14376798E-22
10.00	-.35930136E-23	.12194331E-25	.35930342E-23
20.00	-.89804212E-24	.54022262E-26	.89805836E-24
50.00	-.14364564E-24	.20078359E-26	.14365967E-24
100.00	-.35917776E-25	.95683297E-27	.35930517E-25
200.00	-.90371224E-26	.44013882E-27	.90478341E-26
500.00	-.15261613E-26	.25668751E-27	.15475970E-26
1000.00	-.35470436E-27	.17188740E-27	.39415789E-27
2000.00	-.56462084E-28	.69586378E-28	.89611555E-28
5000.00	.48854712E-30	.12313370E-28	.12323057E-28
10000.00	.16455666E-29	.26542483E-29	.31229670E-29

E(Y) OF A H.E.D.=0 AT THETA=0 AND 90
DEGREES FOR ALL R

EY OF A H.E.D.
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(0,0)= .98058067E-05 N(-1,1)= .99019500E-01

T	REAL EY	IMAG. EY	ABS. EY
.10	.91458621E-21	.00000000E-99	.91458621E-21
.20	.22864655E-21	.00000000E-99	.22864655E-21
.50	.36583443E-22	.00000000E-99	.36583442E-22
1.00	.91458621E-23	.00000000E-99	.91458621E-23
2.00	.22864655E-23	.00000000E-99	.22864655E-23
5.00	.36583443E-24	.00000000E-99	.36583442E-24
10.00	.91458621E-25	.00000000E-99	.91458621E-25
20.00	.22864655E-25	.00000000E-99	.22864655E-25
50.00	.36583443E-26	.00000000E-99	.36583442E-26
100.00	.91458621E-27	.00000000E-99	.91458621E-27
200.00	.22864655E-27	.00000000E-99	.22864655E-27
500.00	.36583443E-28	.00000000E-99	.36583442E-28
1000.00	.91458621E-29	.00000000E-99	.91458621E-29
2000.00	.22864655E-29	.00000000E-99	.22864655E-29
5000.00	.36583443E-30	.00000000E-99	.36583442E-30
10000.00	.91458621E-31	.00000000E-99	.91458621E-31

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(0,0)= .31622777E-05 N(-1,1)= .72075920E-00

T	REAL EY	IMAG. EY	ABS. EY
.10	.15627357E-19	.00000000E-99	.15627357E-19
.20	.39068391E-20	.00000000E-99	.39068391E-20
.50	.62509419E-21	.00000000E-99	.62509419E-21
1.00	.15627357E-21	.00000000E-99	.15627357E-21
2.00	.39068391E-22	.00000000E-99	.39068391E-22
5.00	.62509419E-23	.00000000E-99	.62509419E-23
10.00	.15627357E-23	.00000000E-99	.15627357E-23
20.00	.39068391E-24	.00000000E-99	.39068391E-24
50.00	.62509419E-25	.00000000E-99	.62509419E-25
100.00	.15627357E-25	.00000000E-99	.15627357E-25
200.00	.39068391E-26	.00000000E-99	.39068391E-26
500.00	.62509419E-27	.00000000E-99	.62509419E-27
1000.00	.15627357E-27	.00000000E-99	.15627357E-27
2000.00	.39068391E-28	.00000000E-99	.39068391E-28
5000.00	.62509419E-29	.00000000E-99	.62509419E-29
10000.00	.15627357E-29	.00000000E-99	.15627357E-29

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(0,0)= .19611613E-05 N(-1,1)= .81980390E-00

T	REAL EY	IMAG. EY	ABS. EY
.10	.12538296E-19	.00000000E-99	.12538296E-19
.20	.31345738E-20	.00000000E-99	.31345737E-20
.50	.50153176E-21	.00000000E-99	.50153176E-21
1.00	.12538296E-21	.00000000E-99	.12538296E-21
2.00	.31345738E-22	.00000000E-99	.31345737E-22
5.00	.50153176E-23	.00000000E-99	.50153176E-23
10.00	.12538296E-23	.00000000E-99	.12538296E-23
20.00	.31345738E-24	.00000000E-99	.31345737E-24
50.00	.50153176E-25	.00000000E-99	.50153176E-25
100.00	.12538296E-25	.00000000E-99	.12538296E-25
200.00	.31345738E-26	.00000000E-99	.31345737E-26
500.00	.50153176E-27	.00000000E-99	.50153176E-27
1000.00	.12538296E-27	.00000000E-99	.12538296E-27
2000.00	.31345738E-28	.00000000E-99	.31345737E-28
5000.00	.50153176E-29	.00000000E-99	.50153176E-29
10000.00	.12538296E-29	.00000000E-99	.12538296E-29

H(X) H.E.D.
R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(1,0)= .94286599E-10 N(0,1)= .97097000E-06

T	REAL HX	IMAG. HX	ABS. HX
.10	.91666403E-23	-.94183446E-23	.13142773E-22
.20	.64356251E-23	-.66400317E-23	.92470152E-23
.50	.40122801E-23	-.41861501E-23	.57984691E-23
1.00	.27971794E-23	-.29546208E-23	.40686602E-23
2.00	.19132383E-23	-.21097930E-23	.28481059E-23
5.00	.11025557E-23	-.12296072E-23	.16515335E-23
10.00	.83820111E-24	-.76075933E-24	.11319610E-23
20.00	.70532677E-24	-.54003118E-24	.88832400E-24
50.00	.48338859E-24	-.46317786E-24	.66947610E-24
100.00	.26895350E-24	-.39120866E-24	.47474224E-24
200.00	.11071987E-24	-.27095037E-24	.29269949E-24
500.00	.25007055E-25	-.12314597E-24	.12565938E-24
1000.00	.98375908E-26	-.70991477E-25	.71669853E-25
2000.00	-.18778273E-26	-.34845589E-25	.34896150E-25
5000.00	.15588711E-27	-.12084373E-25	.12085378E-25
10000.00	.50481778E-27	-.64758555E-26	.64955018E-26

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(1,0)= .31622778E-11 N(0,1)= .22792410E-05

T	REAL HX	IMAG. HX	ABS. HX
.10	.73055366E-23	-.73191267E-23	.10341203E-22
.20	.51619718E-23	-.51756933E-23	.73098395E-23
.50	.32596102E-23	-.32730685E-23	.46193112E-23
1.00	.23056533E-23	-.23143526E-23	.32668432E-23
2.00	.16119749E-23	-.16583759E-23	.23127199E-23
5.00	.95297993E-24	-.96939615E-24	.13593747E-23
10.00	.72906625E-24	-.56552609E-24	.92269028E-24
20.00	.64296834E-24	-.32698793E-24	.72133861E-24
50.00	.59266547E-24	-.18879571E-24	.62200979E-24
100.00	.57375005E-24	-.17035251E-24	.59850571E-24
200.00	.52668940E-24	-.24707685E-24	.58176343E-24
500.00	.27503346E-24	-.31983171E-24	.42182427E-24
1000.00	.10569493E-24	-.23472319E-24	.25742259E-24
2000.00	.32005650E-25	-.13562982E-24	.13935497E-24
5000.00	.56022761E-26	-.57239062E-25	.57512569E-25
10000.00	.14305805E-26	-.28885457E-25	.28920860E-25

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA=30,60 DEGREES
N(1,0)= .75429281E-12 N(0,1)= .16077678E-05

T	REAL HX	IMAG. HX	ABS. HX
.10	.18647238E-23	-.18426645E-23	.26215658E-23
.20	.13181738E-23	-.13077113E-23	.18567958E-23
.50	.83311653E-24	-.82974796E-24	.11758251E-23
1.00	.58989594E-24	-.58775283E-24	.83272481E-24
2.00	.41303304E-24	-.42171904E-24	.59029080E-24
5.00	.24474067E-24	-.24670776E-24	.34750929E-24
10.00	.18745055E-24	-.14353995E-24	.23609622E-24
20.00	.16549121E-24	-.82097923E-25	.18473605E-24
50.00	.15213995E-24	-.45642782E-25	.15883899E-24
100.00	.14347558E-24	-.35509896E-25	.14780458E-24
200.00	.13946960E-24	-.33639709E-25	.14346915E-24
500.00	.12050461E-24	-.68698140E-25	.13871119E-24
1000.00	.65817480E-25	-.79015050E-25	.10283636E-24
2000.00	.24281872E-25	-.56594636E-25	.61583781E-25
5000.00	.47504115E-26	-.26280171E-25	.26706062E-25
10000.00	.12513581E-26	-.13519638E-25	.13577426E-25

C H(Y) OF A H. E. D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

N(1,0)= .10000000E-09

T	REAL HY	IMAG. HY	ABS. HY
.10	-.19584650E-21	-.11106470E-18	.11106487E-18
.20	-.13787081E-21	-.55491356E-19	.55491527E-19
.50	-.86422145E-22	-.22164020E-19	.22164188E-19
1.00	-.60622960E-22	-.11063689E-19	.11063854E-19
2.00	-.41856664E-22	-.55183551E-20	.55185137E-20
5.00	-.24364926E-22	-.21991154E-20	.21992503E-20
10.00	-.18596608E-22	-.10968842E-20	.10970417E-20
20.00	-.16156288E-22	-.54595773E-21	.54619672E-21
50.00	-.13036460E-22	-.21395208E-21	.21434887E-21
100.00	-.92522260E-23	-.10292226E-21	.10333728E-21
200.00	-.51795225E-23	-.48552267E-22	.48827758E-22
500.00	-.17020543E-23	-.17993846E-22	.18074165E-22
1000.00	-.58907215E-24	-.86495692E-23	.86696051E-23
2000.00	-.17716192E-24	-.42425050E-23	.42462024E-23
5000.00	-.35286045E-25	-.16801825E-23	.16805529E-23
10000.00	-.10301533E-25	-.83681315E-24	.83687655E-24

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00000000E-99DEGREES

N(1,0)= .94286599E-10 N(0,1)= .97097000E-06

.10	-.18473338E-21	-.10471902E-18	.10471918E-18
.20	-.13006968E-21	-.52320858E-19	.52321019E-19
.50	-.81559865E-22	-.20897678E-19	.20897837E-19
1.00	-.57234228E-22	-.10431565E-19	.10431721E-19
2.00	-.39539979E-22	-.52030593E-20	.52032094E-20
5.00	-.23030512E-22	-.20734650E-20	.20735928E-20
10.00	-.17582652E-22	-.10342373E-20	.10343867E-20
20.00	-.15305209E-22	-.51482989E-21	.51505733E-21
50.00	-.12457637E-22	-.20179976E-21	.20218391E-21
100.00	-.89322359E-23	-.97038128E-22	.97448361E-22
200.00	-.50532408E-23	-.45695966E-22	.45974520E-22
500.00	-.16643881E-23	-.16877682E-22	.16959549E-22
1000.00	-.58672721E-24	-.80990928E-23	.81203172E-23
2000.00	-.17833492E-24	-.39618146E-23	.39658262E-23
5000.00	-.34050858E-25	-.15682155E-23	.15685851E-23
10000.00	-.98498072E-26	-.78141014E-24	.78147221E-24
T	REAL HY	IMAG. HY	ABS. HY

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	-.17944100E-21	-.10472445E-18	.10472460E-18
.20	-.12635407E-21	-.52324688E-19	.52324840E-19
.50	-.79243372E-22	-.20900094E-19	.20900244E-19
1.00	-.55619273E-22	-.10433270E-19	.10433417E-19
2.00	-.38435369E-22	-.52042771E-20	.52044189E-20
5.00	-.22393949E-22	-.20741747E-20	.20742955E-20
10.00	-.17098716E-22	-.10346765E-20	.10348177E-20
20.00	-.14897988E-22	-.51514162E-21	.51535700E-21
50.00	-.12178552E-22	-.20206716E-21	.20243382E-21
100.00	-.87769549E-23	-.97263986E-22	.97659192E-22
200.00	-.49893165E-23	-.45852395E-22	.46123045E-22
500.00	-.16499502E-23	-.16948779E-22	.17028900E-22
1000.00	-.58104742E-24	-.81400787E-23	.81607902E-23
2000.00	-.17941908E-24	-.39819323E-23	.39859724E-23
5000.00	-.33960856E-25	-.15751923E-23	.15755583E-23
10000.00	-.95583503E-26	-.78514895E-24	.78520712E-24

C H(Y) OF A H. E. D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES
N(1,0)= .94286599E-10 N(0,1)= .97097000E-06

T	REAL HY	IMAG. HY	ABS. HY
.10	-.16885629E-21	-.10473532E-18	.10473545E-18
.20	-.11892285E-21	-.52332354E-19	.52332488E-19
.50	-.74610401E-22	-.20904927E-19	.20905059E-19
1.00	-.52389369E-22	-.10436682E-19	.10436813E-19
2.00	-.36226154E-22	-.52067132E-20	.52068391E-20
5.00	-.21120829E-22	-.20755944E-20	.20757018E-20
10.00	-.16130845E-22	-.10355548E-20	.10356804E-20
20.00	-.14083546E-22	-.51576519E-21	.51595743E-21
50.00	-.11620384E-22	-.20260198E-21	.20293495E-21
100.00	-.84663948E-23	-.97715712E-22	.98081803E-22
200.00	-.48614682E-23	-.46165260E-22	.46420523E-22
500.00	-.16210745E-23	-.17090975E-22	.17167682E-22
1000.00	-.56968800E-24	-.82220525E-23	.82417650E-23
2000.00	-.18158741E-24	-.40221685E-23	.40262652E-23
5000.00	-.33780852E-25	-.15891460E-23	.15895049E-23
10000.00	-.89754375E-26	-.79262652E-24	.79267733E-24

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	-.16356393E-21	-.10474076E-18	.10474088E-18
.20	-.11520724E-21	-.52336190E-19	.52336316E-19
.50	-.72293902E-22	-.20907345E-19	.20907469E-19
1.00	-.50774419E-22	-.10438388E-19	.10438510E-19
2.00	-.35121544E-22	-.52079315E-20	.52080499E-20
5.00	-.20484269E-22	-.20763044E-20	.20764054E-20
10.00	-.15646910E-22	-.10359941E-20	.10361122E-20
20.00	-.13676326E-22	-.51607700E-21	.51625818E-21
50.00	-.11341299E-22	-.20286940E-21	.20318616E-21
100.00	-.83111149E-23	-.97941576E-22	.98293575E-22
200.00	-.47975442E-23	-.46321696E-22	.46569473E-22
500.00	-.16066369E-23	-.17162074E-22	.17237112E-22
1000.00	-.56400827E-24	-.82630400E-23	.82822662E-23
2000.00	-.18267159E-24	-.40422865E-23	.40464117E-23
5000.00	-.33690850E-25	-.15961230E-23	.15964784E-23
10000.00	-.86839805E-26	-.79636545E-24	.79641279E-24

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(1,0)= .31622778E-11 N(0,1)= .22792410E-05

T	REAL HY	IMAG. HY	ABS. HY
.10	-.62531020E-23	-.35121735E-20	.35121790E-20
.20	-.44196490E-23	-.17547899E-20	.17547954E-20
.50	-.27924983E-23	-.70088727E-21	.70089283E-21
1.00	-.19765648E-23	-.34986388E-21	.34986944E-21
2.00	-.13832598E-23	-.17450312E-21	.17450860E-21
5.00	-.81900403E-24	-.69539494E-22	.69544316E-22
10.00	-.62704757E-24	-.34701565E-22	.34707228E-22
20.00	-.55341722E-24	-.17315048E-22	.17323889E-22
50.00	-.50900840E-24	-.68810690E-23	.68998695E-23
100.00	-.48616041E-24	-.33913562E-23	.34260251E-23
200.00	-.46571589E-24	-.16065675E-23	.16727074E-23
500.00	-.33340124E-24	-.45958564E-24	.56778107E-24
1000.00	-.17577045E-24	-.12029917E-24	.21299563E-24
2000.00	-.70540778E-25	-.15106836E-25	.72140264E-25
5000.00	-.16373027E-25	.67924317E-26	.17726057E-25
10000.00	-.48783166E-26	.54525194E-26	.73162791E-26

H(Y) H.E.D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,0)= .31622778E-11 N(0,1)= .22792410E-05

T	REAL HY	IMAG. HY	ABS. HY
.10	-.20352483E-23	-.35163991E-20	.35163997E-20
.20	-.14393832E-23	-.17577780E-20	.17577785E-20
.50	-.91056143E-24	-.70277696E-21	.70277754E-21
1.00	-.64539517E-24	-.35120005E-21	.35120064E-21
2.00	-.45258564E-24	-.17546058E-21	.17546116E-21
5.00	-.26880078E-24	-.70099169E-22	.70099684E-22
10.00	-.20612094E-24	-.35028071E-22	.35028676E-22
20.00	-.18219929E-24	-.17503833E-22	.17504781E-22
50.00	-.16683281E-24	-.69900699E-23	.69920604E-23
100.00	-.15490564E-24	-.34897092E-23	.34931454E-23
200.00	-.16163162E-24	-.17492174E-23	.17566690E-23
500.00	-.17461058E-24	-.64424055E-24	.66748388E-24
1000.00	-.11474745E-24	-.25581665E-24	.28037320E-24
2000.00	-.52062303E-25	-.93412736E-25	.10694120E-24
5000.00	-.13138550E-25	-.26254554E-25	.29358527E-25
10000.00	-.40523704E-26	-.11224506E-25	.11933617E-25

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	.64004571E-23	-.35248505E-20	.35248561E-20
.20	.45211472E-23	-.17637543E-20	.17637600E-20
.50	.28533115E-23	-.70655641E-21	.70656216E-21
1.00	.20169435E-23	-.35387243E-21	.35387817E-21
2.00	.14087623E-23	-.17737552E-21	.17738111E-21
5.00	.83160557E-24	-.71218530E-22	.71223384E-22
10.00	.63573212E-24	-.35681086E-22	.35686748E-22
20.00	.56023648E-24	-.17881407E-22	.17890181E-22
50.00	.51751825E-24	-.72080722E-23	.72266264E-23
100.00	.50760376E-24	-.36864151E-23	.37211983E-23
200.00	.44653682E-24	-.20345171E-23	.20829438E-23
500.00	.14297065E-24	-.10135504E-23	.10235843E-23
1000.00	.72985125E-26	-.52685160E-24	.52690214E-24
2000.00	-.15105367E-25	-.25002453E-24	.25048041E-24
5000.00	-.66696011E-26	-.92348521E-25	.92589053E-25
10000.00	-.24004785E-26	-.44578552E-25	.44643134E-25

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	.10618312E-22	-.35290762E-20	.35290920E-20
.20	.75014137E-23	-.17667425E-20	.17667584E-20
.50	.47352486E-23	-.70844610E-21	.70846192E-21
1.00	.33481133E-23	-.35520862E-21	.35522437E-21
2.00	.23394366E-23	-.17833298E-21	.17834832E-21
5.00	.13818088E-23	-.71778212E-22	.71791510E-22
10.00	.10566588E-23	-.36007592E-22	.36023092E-22
20.00	.93145447E-24	-.18070194E-22	.18094184E-22
50.00	.85969389E-24	-.73170734E-23	.73674036E-23
100.00	.83885854E-24	-.37847684E-23	.38766164E-23
200.00	.75062113E-24	-.21771670E-23	.23029303E-23
500.00	.30176131E-24	-.11982053E-23	.12356195E-23
1000.00	.68321512E-25	-.66236912E-24	.66588337E-24
2000.00	.33731079E-26	-.32833044E-24	.32834775E-24
5000.00	-.34351250E-26	-.12539550E-24	.12544254E-24
10000.00	-.15745328E-26	-.61255577E-25	.61275809E-25

H(Y) H.E.D.

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .00000000E-99DEGREES
N(1,0)= .75429281E-12 N(0,1)= .16077678E-05

T	REAL HY	IMAG. HY	ABS. HY
.10	-.14924670E-23	-.83775254E-21	.83775386E-21
.20	-.10551551E-23	-.41856701E-21	.41856833E-21
.50	-.66704530E-24	-.16718146E-21	.16718278E-21
1.00	-.47244159E-24	-.83452403E-22	.83453740E-22
2.00	-.33092904E-24	-.41623895E-22	.41625209E-22
5.00	-.19621301E-24	-.16587135E-22	.16588295E-22
10.00	-.15033976E-24	-.82775147E-23	.82788798E-23
20.00	-.13279383E-24	-.41307008E-23	.41328347E-23
50.00	-.12227218E-24	-.16425054E-23	.16470502E-23
100.00	-.11537481E-24	-.81122152E-24	.81938494E-24
200.00	-.10892733E-24	-.39433500E-24	.40910298E-24
500.00	-.10167292E-24	-.12865693E-24	.16398167E-24
1000.00	-.73101667E-25	-.27815483E-25	.78214798E-25
2000.00	-.36823140E-25	.95615027E-26	.38044262E-25
5000.00	-.10193680E-25	.12682691E-25	.16271501E-25
10000.00	-.32802180E-26	.80165037E-26	.86616489E-26

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	-.41586823E-24	-.83881632E-21	.83881642E-21
.20	-.29410703E-24	-.41932198E-21	.41932207E-21
.50	-.18604520E-24	-.16766050E-21	.16766060E-21
1.00	-.13186499E-24	-.83791732E-22	.83791835E-22
2.00	-.92464320E-25	-.41867371E-22	.41867473E-22
5.00	-.54911920E-25	-.16729570E-22	.16729659E-22
10.00	-.42115126E-25	-.83603870E-23	.83604930E-23
20.00	-.37247434E-25	-.41780998E-23	.41782657E-23
50.00	-.34434133E-25	-.16688570E-23	.16692122E-23
100.00	-.32539145E-25	-.83172310E-24	.83235936E-24
200.00	-.28404516E-25	-.41375687E-24	.41473070E-24
500.00	-.32099543E-25	-.16831980E-24	.17135324E-24
1000.00	-.35101926E-25	-.73434843E-25	.81393005E-25
2000.00	-.22803995E-25	-.23113426E-25	.32469256E-25
5000.00	-.74510282E-26	-.24901728E-26	.78561301E-26
10000.00	-.25577460E-26	.21093673E-27	.25664292E-26

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HY	IMAG. HY	ABS. HY
.10	.17373289E-23	-.84094411E-21	.84094590E-21
.20	.12279887E-23	-.42083201E-21	.42083379E-21
.50	.77595483E-24	-.16861862E-21	.16862040E-21
1.00	.54928808E-24	-.84470417E-22	.84472202E-22
2.00	.38446503E-24	-.42354331E-22	.42356076E-22
5.00	.22769021E-24	-.17014444E-22	.17015967E-22
10.00	.17433410E-24	-.85261328E-23	.85279149E-23
20.00	.15384533E-24	-.42728983E-23	.42756669E-23
50.00	.14124192E-24	-.17215609E-23	.17273451E-23
100.00	.13313216E-24	-.87272639E-24	.88282247E-24
200.00	.13264108E-24	-.45260066E-24	.47163652E-24
500.00	.10704718E-24	-.24764559E-24	.26979146E-24
1000.00	.40897547E-25	-.16467355E-24	.16967612E-24
2000.00	.52342904E-26	-.88463270E-25	.88617988E-25
5000.00	-.19657265E-26	-.32835896E-25	.32894681E-25
10000.00	-.11128024E-26	-.15400194E-25	.15440346E-25

H(Y) H.E.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES
N(1,0)= .75429281E-12 N(0,1)= .16077678E-05

T	REAL HY	IMAG. HY	ABS. HY
.10	.28139279E-23	-.84200800E-21	.84201269E-21
.20	.19890369E-23	-.42158704E-21	.42159172E-21
.50	.12569550E-23	-.16909768E-21	.16910234E-21
1.00	.88986468E-24	-.84809757E-22	.84814425E-22
2.00	.62292981E-24	-.42597813E-22	.42602367E-22
5.00	.36899133E-24	-.17156882E-22	.17160849E-22
10.00	.28255874E-24	-.86090056E-23	.86136412E-23
20.00	.24939174E-24	-.43202976E-23	.43274896E-23
50.00	.22907998E-24	-.17479128E-23	.17628604E-23
100.00	.21596785E-24	-.89322809E-24	.91896601E-24
200.00	.21316391E-24	-.47202259E-24	.51792294E-24
500.00	.17662055E-24	-.28730849E-24	.33725506E-24
1000.00	.78897288E-25	-.21029292E-24	.22460608E-24
2000.00	.19253439E-25	-.12113821E-24	.12265871E-24
5000.00	.77692532E-27	-.48008763E-25	.48015048E-25
10000.00	-.39033039E-27	-.23205761E-25	.23209043E-25

H(Z) OF A H.E.D. =0 AT THETA=0 FOR
ALL R

THE H(Z) OF A H.E.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .29999999E+02DEGREES
N(1,1)= .18857319E-10

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.53112838E-22	-.53837214E-22	.75626841E-22
.20	.37344953E-22	-.38066429E-22	.53326339E-22
.50	.23352739E-22	-.24070560E-22	.33537176E-22
1.00	.16336402E-22	-.17016454E-22	.23588932E-22
2.00	.11232356E-22	-.12169769E-22	.16561071E-22
5.00	.65080233E-23	-.71002476E-23	.96316085E-23
10.00	.49616031E-23	-.43270544E-23	.65833809E-23
20.00	.42618337E-23	-.29555490E-23	.51863759E-23
50.00	.32111255E-23	-.25337858E-23	.40904030E-23
100.00	.20304282E-23	-.23276744E-23	.30888034E-23
200.00	.96945318E-24	-.17767215E-23	.20240006E-23
500.00	.25085166E-24	-.93264834E-24	.96579474E-24
1000.00	.75148105E-25	-.50323943E-24	.50881936E-24
2000.00	.20471130E-25	-.25890433E-24	.25971237E-24
5000.00	.34169391E-26	-.10461895E-24	.10467473E-24
10000.00	.87120662E-27	-.52405119E-25	.52412360E-25

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .59999996E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.91994129E-22	-.93248784E-22	.13098952E-21
.20	.64683351E-22	-.65932984E-22	.92363923E-22
.50	.40448128E-22	-.41691430E-22	.58088091E-22
1.00	.28295477E-22	-.29473361E-22	.40857227E-22
2.00	.19455010E-22	-.21078657E-22	.28684615E-22
5.00	.11272227E-22	-.12297989E-22	.16682434E-22
10.00	.85937482E-23	-.74946777E-23	.11402749E-22
20.00	.73817119E-23	-.51191606E-23	.89830660E-23
50.00	.55618323E-23	-.43886455E-23	.70847856E-23
100.00	.35168046E-23	-.40316501E-23	.53499642E-23
200.00	.16791420E-23	-.30773717E-23	.35056716E-23
500.00	.43448781E-24	-.16153943E-23	.16728055E-23
1000.00	.13016033E-24	-.87163620E-24	.88130095E-24
2000.00	.35457034E-25	-.44843542E-24	.44983500E-24
5000.00	.59183119E-26	-.18120534E-24	.18130196E-24
10000.00	.15089740E-26	-.90768323E-25	.90780865E-25

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= .89999992E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.10622567E-21	-.10767443E-21	.15125368E-21
.20	.74689904E-22	-.76132855E-22	.10665267E-21
.50	.46705477E-22	-.48141119E-22	.67074353E-22
1.00	.32672804E-22	-.34032907E-22	.47177864E-22
2.00	.22464712E-22	-.24339538E-22	.33122143E-22
5.00	.13016047E-22	-.14200495E-22	.19263217E-22
10.00	.99232061E-23	-.86541087E-23	.13166761E-22
20.00	.85236670E-23	-.59110978E-23	.10372751E-22
50.00	.64222510E-23	-.50675715E-23	.81808061E-23
100.00	.40608564E-23	-.46553487E-23	.61776068E-23
200.00	.19389063E-23	-.35534429E-23	.40480011E-23
500.00	.50170333E-24	-.18652967E-23	.19315895E-23
1000.00	.15029621E-24	-.10064788E-23	.10176386E-23
2000.00	.40942258E-25	-.51780864E-24	.51942472E-24
5000.00	.68338782E-26	-.20923791E-24	.20934947E-24
10000.00	.17424132E-26	-.10481024E-24	.10482472E-24

THE H(Z) OF A H.E.D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,1)= .94868334E-11

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.28218992E-23	-.28168086E-23	.39871700E-23
.20	.19968480E-23	-.19918796E-23	.28204585E-23
.50	.12646205E-23	-.12597212E-23	.17849824E-23
1.00	.89745873E-24	-.89072982E-24	.12644491E-23
2.00	.63050679E-24	-.63854051E-24	.89736992E-24
5.00	.37540383E-24	-.37328560E-24	.52940549E-24
10.00	.28796848E-24	-.21559252E-24	.35973042E-24
20.00	.25423076E-24	-.11959177E-24	.28095456E-24
50.00	.23256304E-24	-.53403230E-25	.23861574E-24
100.00	.23114712E-24	-.13546227E-25	.23154371E-24
200.00	.27881798E-24	-.10237095E-25	.27900584E-24
500.00	.24769421E-24	-.13630472E-24	.28272141E-24
1000.00	.12632238E-24	-.15578618E-24	.20056589E-24
2000.00	.45882309E-25	-.10883075E-24	.11810723E-24
5000.00	.91994504E-26	-.50383868E-25	.51216833E-25
10000.00	.24818097E-26	-.25993899E-25	.26112107E-25

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.48876725E-23	-.48788554E-23	.69059808E-23
.20	.34586419E-23	-.34500363E-23	.48851769E-23
.50	.21903869E-23	-.21819010E-23	.30916802E-23
1.00	.15544440E-23	-.15427892E-23	.21900900E-23
2.00	.10920697E-23	-.11059845E-23	.15542901E-23
5.00	.65021848E-24	-.64654960E-24	.91695717E-24
10.00	.49877602E-24	-.37341718E-24	.62307135E-24
20.00	.44034055E-24	-.20713901E-24	.48662753E-24
50.00	.40281099E-24	-.92497104E-25	.41329456E-24
100.00	.40035854E-24	-.23462753E-25	.40104545E-24
200.00	.48292687E-24	-.17731168E-25	.48325226E-24
500.00	.42901895E-24	-.23608670E-24	.48968784E-24
1000.00	.21879676E-24	-.26982957E-24	.34739028E-24
2000.00	.79470483E-25	-.18850037E-24	.20456770E-24
5000.00	.15933915E-25	-.87267416E-25	.88710154E-25
10000.00	.42986202E-26	-.45022750E-25	.45227492E-25

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.56437983E-23	-.56336172E-23	.79743402E-23
.20	.39936958E-23	-.39837590E-23	.56409167E-23
.50	.25292410E-23	-.25194423E-23	.35699648E-23
1.00	.17949174E-23	-.17814596E-23	.25288983E-23
2.00	.12610135E-23	-.12770810E-23	.17947397E-23
5.00	.75080766E-24	-.74657120E-24	.10588109E-23
10.00	.57593696E-24	-.43118503E-24	.71946084E-24
20.00	.50846149E-24	-.23918353E-24	.56190911E-24
50.00	.46512609E-24	-.10680646E-24	.47723149E-24
100.00	.46229424E-24	-.27092454E-25	.46308742E-24
200.00	.55763594E-24	-.20474190E-25	.55801167E-24
500.00	.49538843E-24	-.27260945E-24	.56544284E-24
1000.00	.25264475E-24	-.31157236E-24	.40113177E-24
2000.00	.91764614E-25	-.21766149E-24	.23621445E-24
5000.00	.18398901E-25	-.10076774E-24	.10243366E-24
10000.00	.49636192E-26	-.51987796E-25	.52224212E-25

THE H(Z) OF A H.E.D.

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .29999999E+02DEGREES

N(1,1)= .37714640E-11

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.43103820E-24	-.45002960E-24	.62315372E-24
.20	.30516706E-24	-.31412227E-24	.43794946E-24
.50	.19345224E-24	-.19628955E-24	.27559636E-24
1.00	.13744482E-24	-.13794899E-24	.19473315E-24
2.00	.96717633E-25	-.98466053E-25	.13802124E-24
5.00	.57734212E-25	-.57360341E-25	.81384567E-25
10.00	.44373472E-25	-.32978249E-25	.55286254E-25
20.00	.39303811E-25	-.18060153E-25	.43254580E-25
100.00	.33956807E-25	-.37191209E-26	.34159866E-25
200.00	.32662255E-25	.61153428E-26	.33229810E-25
500.00	.57838587E-25	.46284257E-26	.58023481E-25
1000.00	.52187497E-25	-.23812899E-25	.57363654E-25
2000.00	.26177058E-25	-.30585051E-25	.40257716E-25
5000.00	.64482419E-26	-.18246585E-25	.19352459E-25
10000.00	.18719131E-26	-.99977503E-26	.10171482E-25

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .59999996E+02DEGREES

N(1,1)= .37714640E-11

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.74658002E-24	-.77947408E-24	.10793338E-23
.20	.52856481E-24	-.54407569E-24	.75855067E-24
.50	.33506909E-24	-.33998346E-24	.47734688E-24
1.00	.23806140E-24	-.23893465E-24	.33728769E-24
2.00	.16751984E-24	-.17054819E-24	.23905978E-24
5.00	.99998584E-25	-.99351022E-25	.14096220E-24
10.00	.76857103E-25	-.57119999E-25	.95758595E-25
20.00	.68076193E-25	-.31281100E-25	.74919125E-25
50.00	.63139818E-25	-.14063390E-25	.64687058E-25
100.00	.58814911E-25	-.64417060E-26	.59166623E-25
200.00	.56572680E-25	.10592084E-25	.57555714E-25
500.00	.10017937E-24	.80166681E-26	.10049961E-24
1000.00	.90391392E-25	-.41245149E-25	.99356761E-25
2000.00	.45339991E-25	-.52974857E-25	.69728403E-25
5000.00	.11168682E-25	-.31604010E-25	.33519440E-25
10000.00	.32422483E-26	-.17316610E-25	.17617523E-25

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .89999992E+02DEGREES

T	REAL HZ	IMAG. HZ	ABS. HZ
.10	.86207639E-24	-.90005917E-24	.12463074E-23
.20	.61033410E-24	-.62824452E-24	.87589890E-24
.50	.38690447E-24	-.39257910E-24	.55119272E-24
1.00	.27488964E-24	-.27589798E-24	.38946630E-24
2.00	.19343526E-24	-.19693210E-24	.27604248E-24
5.00	.11546842E-24	-.11472068E-24	.16276913E-24
10.00	.88746942E-25	-.65956497E-25	.11057250E-24
20.00	.78607620E-25	-.36120305E-25	.86509157E-25
50.00	.72907584E-25	-.16239005E-25	.74694183E-25
100.00	.67913612E-25	-.74382417E-26	.68319734E-25
200.00	.65324507E-25	.12230685E-25	.66459617E-25
500.00	.11567717E-24	.92568514E-26	.11604696E-24
1000.00	.10437499E-24	-.47625798E-25	.11472730E-24
2000.00	.52354114E-25	-.61170099E-25	.80515428E-25
5000.00	.12896484E-25	-.36493169E-25	.38704918E-25
10000.00	.37438260E-26	-.19995500E-25	.20342965E-25

APPENDIX XI

Absolute values of the horizontal E and H fields on the earth's surface of the horizontal dipoles, the angles the fields make with the x-axis (denoted by angle), and the phase angles of their x- and y-components (denoted by phasx and phasy).

Since these angles are computed from arctan (y-component/x-component), a positive angle can be either in the 1st or 3rd quadrant, and a negative angle can be either in the 2nd or 4th quadrant. When in doubt, one should check the field components in Appendix X. When the x-component is equal to zero, the angle is automatically set as equal to 90°; this is not valid if the y-component is also zero. Therefore one has to be very careful in using these tables.

See front page of Appendix IX for meaning of other symbols.

[illegible]

[illegible]

[illegible]

[illegible]

HOR. MAGN. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.32984194E-16	90.00	90.00	-45.25
.20	.23280152E-16	90.00	90.00	-45.36
.50	.14667514E-16	90.00	90.00	-45.59
1.00	.10337176E-16	90.00	90.00	-45.78
2.00	.72793801E-17	90.00	90.00	-46.76
5.00	.42479850E-17	90.00	90.00	-46.79
10.00	.28938173E-17	90.00	90.00	-39.85
20.00	.22824689E-17	90.00	90.00	-31.71
50.00	.18878124E-17	90.00	90.00	-31.47
100.00	.15394028E-17	90.00	90.00	-39.96
200.00	.11052490E-17	90.00	90.00	-51.95
500.00	.58821792E-18	90.00	90.00	-67.18
1000.00	.32622230E-18	90.00	90.00	-75.79
2000.00	.17274752E-18	90.00	90.00	-81.36
5000.00	.71428007E-19	90.00	90.00	-86.16
10000.00	.35895817E-19	90.00	90.00	-88.03

R= .20 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.34112455E-16	86.86	-45.77	-45.26
.20	.24073907E-16	86.87	-45.89	-45.38
.50	.15165111E-16	86.88	-46.21	-45.61
1.00	.10686258E-16	86.90	-46.56	-45.81
2.00	.75236638E-17	86.91	-47.79	-46.79
5.00	.43895851E-17	86.93	-48.11	-46.83
10.00	.29908439E-17	86.91	-42.22	-39.93
20.00	.23583041E-17	86.93	-37.43	-31.89
50.00	.19437865E-17	87.19	-43.77	-31.81
100.00	.15783688E-17	87.55	-55.49	-40.33
200.00	.11291160E-17	87.89	-67.77	-52.28
500.00	.59858612E-18	88.29	-78.52	-67.37
1000.00	.33221757E-18	88.24	-82.11	-75.90
2000.00	.17561908E-18	88.38	86.91	-81.55
5000.00	.72437494E-19	88.64	-89.26	-86.20
10000.00	.36439405E-19	88.54	-85.54	-87.99

R= .20 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.36263869E-16	87.05	-45.77	-45.29
.20	.25587599E-16	87.05	-45.89	-45.41
.50	.16114293E-16	87.07	-46.21	-45.64
1.00	.11352272E-16	87.08	-46.56	-45.85
2.00	.79898530E-17	87.09	-47.79	-46.85
5.00	.46598957E-17	87.11	-48.11	-46.91
10.00	.31760163E-17	87.09	-42.22	-40.06
20.00	.25030911E-17	87.11	-37.43	-32.21
50.00	.20511569E-17	87.34	-43.77	-32.45
100.00	.16535484E-17	87.66	-55.49	-41.04
200.00	.11753972E-17	87.97	-67.77	-52.91
500.00	.61880153E-18	88.34	-78.52	-67.74
1000.00	.34389476E-18	88.30	-82.11	-76.11
2000.00	.18122569E-18	88.43	86.91	-81.91
5000.00	.74415396E-19	88.67	-89.26	-86.28
10000.00	.37502949E-19	88.59	-85.54	-87.92

HOR. MAGN. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.37293090E-16	89.99	-45.77	-45.31
.20	.26311838E-16	89.99	-45.89	-45.42
.50	.16568506E-16	89.99	-46.21	-45.66
1.00	.11671038E-16	89.99	-46.56	-45.87
2.00	.82130376E-17	89.99	-47.79	-46.88
5.00	.47893350E-17	89.99	-48.11	-46.94
10.00	.32646672E-17	89.99	-42.22	-40.12
20.00	.25724306E-17	89.99	-37.43	-32.36
50.00	.21027873E-17	89.99	-43.77	-32.74
100.00	.16898846E-17	89.99	-55.49	-41.37
200.00	.11978676E-17	89.99	-67.77	-53.20
500.00	.62866553E-18	89.99	-78.52	-67.92
1000.00	.34958714E-18	89.99	-82.11	-76.21
2000.00	.18396496E-18	89.99	86.91	-82.08
5000.00	.75384887E-19	89.99	-89.26	-86.32
10000.00	.38023570E-19	89.99	-85.54	-87.89

R=3.00 THETA=00.DEGREES

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.21343036E-17	90.00	90.00	-45.06
.20	.15085228E-17	90.00	90.00	-45.09
.50	.95314440E-18	90.00	90.00	-45.14
1.00	.67393887E-18	90.00	90.00	-45.14
2.00	.47696874E-18	90.00	90.00	-45.86
5.00	.28023069E-18	90.00	90.00	-45.56
10.00	.19016908E-18	90.00	90.00	-37.92
20.00	.14863591E-18	90.00	90.00	-27.16
50.00	.12836991E-18	90.00	90.00	-18.05
100.00	.12495091E-18	90.00	90.00	-17.61
200.00	.12197127E-18	90.00	90.00	-29.10
500.00	.82245519E-19	90.00	90.00	-58.60
1000.00	.45139686E-19	90.00	90.00	-77.59
2000.00	.21642728E-19	90.00	90.00	-88.73
5000.00	.78273528E-20	90.00	90.00	86.42
10000.00	.37080706E-20	90.00	90.00	86.54

R=3.00 THETA=30.DEGREES

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.19521675E-17	41.23	-45.05	-45.07
.20	.13798244E-17	41.22	-45.07	-45.10
.50	.87186219E-18	41.21	-45.11	-45.16
1.00	.61650365E-18	41.21	-45.10	-45.17
2.00	.43635468E-18	41.19	-45.81	-45.90
5.00	.25640075E-18	41.17	-45.48	-45.62
10.00	.17400810E-18	41.16	-37.80	-38.00
20.00	.13601358E-18	41.15	-26.95	-27.30
50.00	.11741783E-18	41.22	-17.66	-18.30
100.00	.11393797E-18	41.77	-16.53	-18.31
200.00	.11121169E-18	42.04	-25.13	-31.65
500.00	.77029774E-19	38.97	-49.30	-65.23
1000.00	.44204262E-19	34.23	-65.75	-87.61
2000.00	.22509798E-19	28.48	-76.72	78.47
5000.00	.87921489E-20	21.77	-84.40	73.12
10000.00	.43304950E-20	18.53	-87.16	75.66

HOR. MAGN. DIPOLE

THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R=3.0 THETA=60.DEGREES

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.15239302E-17	15.55	-45.05	-44.99
.20	.10772514E-17	15.55	-45.07	-44.99
.50	.68078714E-18	15.57	-45.11	-44.97
1.00	.48149861E-18	15.58	-45.10	-44.90
2.00	.34090868E-18	15.60	-45.81	-45.53
5.00	.20041301E-18	15.64	-45.48	-45.07
10.00	.13604396E-18	15.65	-37.80	-37.16
20.00	.10636640E-18	15.67	-26.95	-25.86
50.00	.91668853E-19	15.56	-17.66	-15.66
100.00	.87864232E-19	14.74	-16.53	-10.50
200.00	.85732962E-19	15.55	-25.13	-3.54
500.00	.65361363E-19	23.61	-49.30	-18.80
1000.00	.42271354E-19	30.16	-65.75	-39.92
2000.00	.24150723E-19	34.99	-76.72	-57.74
5000.00	.10458046E-19	38.67	-84.40	-73.41
10000.00	.53628328E-20	40.03	-87.16	-80.40

R=3.0 THETA=90 DEGREES

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.12562040E-17	89.99	-45.05	-45.03
.20	.88810131E-18	89.99	-45.07	-45.04
.50	.56136652E-18	89.99	-45.11	-45.07
1.00	.39714185E-18	89.99	-45.10	-45.04
2.00	.28129183E-18	89.99	-45.81	-45.72
5.00	.16546079E-18	89.99	-45.48	-45.35
10.00	.11234996E-18	89.99	-37.80	-37.59
20.00	.87868498E-19	89.99	-26.95	-26.59
50.00	.75573079E-19	89.99	-17.66	-17.01
100.00	.71339004E-19	89.99	-16.53	-14.64
200.00	.69578656E-19	89.99	-25.13	-18.14
500.00	.58663180E-19	89.99	-49.30	-36.20
1000.00	.41270963E-19	89.99	-65.75	-52.79
2000.00	.24930716E-19	89.99	-76.72	-66.31
5000.00	.11198444E-19	89.99	-84.40	-78.01
10000.00	.58106256E-20	89.99	-87.16	-83.15

R= 5.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.55976596E-18	90.00	90.00	-44.46
.20	.39684279E-18	90.00	90.00	-44.63
.50	.25151524E-18	90.00	90.00	-44.80
1.00	.17819014E-18	90.00	90.00	-44.84
2.00	.12633803E-18	90.00	90.00	-45.57
5.00	.74383053E-19	90.00	90.00	-45.22
10.00	.50540246E-19	90.00	90.00	-37.46
20.00	.39545367E-19	90.00	90.00	-26.44
50.00	.33982960E-19	90.00	90.00	-16.85
100.00	.31604185E-19	90.00	90.00	-14.03
200.00	.31163749E-19	90.00	90.00	-13.81
500.00	.30271640E-19	90.00	90.00	-34.07
1000.00	.21150026E-19	90.00	90.00	-58.02
2000.00	.11568151E-19	90.00	90.00	-76.33
5000.00	.44342124E-20	90.00	90.00	-88.57
10000.00	.21037700E-20	90.00	90.00	88.49

HOR. MAGN. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= 5.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.50741238E-18	42.82	-44.65	-44.34
.20	.35964212E-18	42.86	-44.77	-44.55
.50	.22788969E-18	42.90	-44.88	-44.75
1.00	.16143738E-18	42.91	-44.89	-44.81
2.00	.11445458E-18	42.92	-45.59	-45.55
5.00	.67385014E-19	42.93	-45.22	-45.22
10.00	.45784301E-19	42.93	-37.44	-37.47
20.00	.35824162E-19	42.93	-26.38	-26.48
50.00	.30789446E-19	42.91	-16.69	-16.95
100.00	.28638255E-19	42.88	-13.90	-14.11
200.00	.28131716E-19	43.61	-13.56	-13.96
500.00	.27333269E-19	43.90	-29.68	-36.70
1000.00	.19449500E-19	41.35	-50.20	-63.13
2000.00	.10980694E-19	37.22	-66.77	-83.57
5000.00	.44323476E-20	31.19	-79.75	83.01
10000.00	.21749332E-20	27.59	-84.71	80.97

R= 5.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.38174277E-18	12.84	-44.65	-45.93
.20	.27029518E-18	12.77	-44.77	-45.66
.50	.17111817E-18	12.70	-44.88	-45.40
1.00	.12117204E-18	12.66	-44.89	-45.21
2.00	.85889295E-19	12.65	-45.59	-45.75
5.00	.50562287E-19	12.64	-45.22	-45.22
10.00	.34350753E-19	12.63	-37.44	-37.29
20.00	.26878245E-19	12.63	-26.38	-25.95
50.00	.23114646E-19	12.68	-16.69	-15.63
100.00	.21512788E-19	12.73	-13.90	-13.01
200.00	.20780326E-19	11.42	-13.56	-11.66
500.00	.20213317E-19	13.03	-29.68	.83
1000.00	.15498451E-19	19.60	-50.20	-16.63
2000.00	.96996234E-20	25.66	-66.77	-39.57
5000.00	.44286168E-20	31.11	-79.75	-62.46
10000.00	.23106941E-20	33.46	-84.71	-73.44

R= 5.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.29976357E-18	89.99	-44.65	-45.02
.20	.21193909E-18	89.99	-44.77	-45.02
.50	.13399751E-18	89.99	-44.88	-45.03
1.00	.94831437E-19	89.99	-44.89	-44.98
2.00	.67197732E-19	89.99	-45.59	-45.64
5.00	.39553107E-19	89.99	-45.22	-45.22
10.00	.26867466E-19	89.99	-37.44	-37.40
20.00	.21023199E-19	89.99	-26.38	-26.26
50.00	.18095173E-19	89.99	-16.69	-16.40
100.00	.16856014E-19	89.99	-13.90	-13.65
200.00	.15875648E-19	89.99	-13.56	-13.06
500.00	.15469762E-19	89.99	-29.68	-21.08
1000.00	.13082868E-19	89.99	-50.20	-37.50
2000.00	.89908952E-20	89.99	-66.77	-54.44
5000.00	.44267501E-20	89.99	-79.75	-70.91
10000.00	.23756671E-20	89.99	-84.71	-78.69

HOR. MAGN. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.16603492E-14	.00	-.26	90.00
.20	.16571296E-14	.00	-.37	90.00
.50	.16507604E-14	.00	-.59	90.00
1.00	.16436119E-14	.00	-.83	90.00
2.00	.16331222E-14	.00	-1.15	90.00
5.00	.16172727E-14	.00	-1.69	90.00
10.00	.16073824E-14	.00	-2.59	90.00
20.00	.15893819E-14	.00	-4.56	90.00
50.00	.15079392E-14	.00	-9.41	90.00
100.00	.13626466E-14	.00	-13.73	90.00
200.00	.11678290E-14	.00	-15.79	90.00
500.00	.95857120E-15	.00	-12.72	90.00
1000.00	.88037895E-15	.00	-8.24	90.00
2000.00	.84968969E-15	.00	-4.70	90.00
5000.00	.83698455E-15	.00	-2.02	90.00
10000.00	.83485017E-15	.00	-1.02	90.00

R= .20 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.17168247E-14	3.11	-.27	-.48
.20	.17134011E-14	3.11	-.38	-.68
.50	.17066289E-14	3.10	-.60	-1.06
1.00	.16990291E-14	3.09	-.85	-1.49
2.00	.16878823E-14	3.07	-1.18	-2.05
5.00	.16710411E-14	3.05	-1.73	-3.00
10.00	.16603971E-14	3.03	-2.65	-4.61
20.00	.16407633E-14	2.97	-4.65	-7.82
50.00	.15535367E-14	2.80	-9.54	-13.79
100.00	.14014865E-14	2.64	-13.79	-16.11
200.00	.12008238E-14	2.62	-15.74	-13.92
500.00	.98800892E-15	2.84	-12.56	-7.26
1000.00	.90913058E-15	3.00	-8.13	-4.60
2000.00	.87796004E-15	3.05	-4.62	-2.05
5000.00	.86551085E-15	3.12	-1.97	-.62
10000.00	.86339237E-15	3.13	-1.00	-.41

R= .20 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.18245390E-14	2.93	-.28	-.48
.20	.18207342E-14	2.93	-.40	-.68
.50	.18132092E-14	2.92	-.63	-1.06
1.00	.18047660E-14	2.91	-.88	-1.49
2.00	.17923903E-14	2.89	-1.23	-2.05
5.00	.17736948E-14	2.87	-1.80	-3.00
10.00	.17616468E-14	2.85	-2.77	-4.61
20.00	.17389778E-14	2.81	-4.83	-7.82
50.00	.16409350E-14	2.65	-9.76	-13.79
100.00	.14761036E-14	2.51	-13.91	-16.11
200.00	.12642328E-14	2.49	-15.65	-13.92
500.00	.10443979E-14	2.69	-12.27	-7.26
1000.00	.96406489E-15	2.83	-7.93	-4.60
2000.00	.93193156E-15	2.88	-4.47	-2.05
5000.00	.91991353E-15	2.94	-1.89	-.62
10000.00	.91781781E-15	2.94	-.96	-.41

HOR. MAGN. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH
R= .20 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.18760785E-14	.00	-.29	-.48
.20	.18720947E-14	.00	-.41	-.68
.50	.18642160E-14	.00	-.64	-1.06
1.00	.18553764E-14	.00	-.90	-1.49
2.00	.18424228E-14	.00	-1.25	-2.05
5.00	.18228552E-14	.00	-1.83	-3.00
10.00	.18101494E-14	.00	-2.82	-4.61
20.00	.17860608E-14	.00	-4.92	-7.82
50.00	.16829330E-14	.00	-9.87	-13.79
100.00	.15120321E-14	.00	-13.96	-16.11
200.00	.12947736E-14	.00	-15.61	-13.92
500.00	.10714802E-14	.00	-12.14	-7.26
1000.00	.99039006E-15	.00	-7.83	-4.60
2000.00	.95777752E-15	.00	-4.40	-2.05
5000.00	.94594231E-15	.00	-1.86	-.62
10000.00	.94385442E-15	.00	-.95	-.41

R= 3.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10739936E-15	.00	-.06	90.00
.20	.10735048E-15	.00	-.08	90.00
.50	.10725355E-15	.00	-.14	90.00
1.00	.10714446E-15	.00	-.20	90.00
2.00	.10698311E-15	.00	-.28	90.00
5.00	.10673736E-15	.00	-.42	90.00
10.00	.10661748E-15	.00	-.64	90.00
20.00	.10652397E-15	.00	-1.13	90.00
50.00	.10652544E-15	.00	-2.61	90.00
100.00	.10715061E-15	.00	-5.56	90.00
200.00	.10378518E-15	.00	-13.24	90.00
500.00	.78146301E-16	.00	-22.89	90.00
1000.00	.60167069E-16	.00	-18.35	90.00
2000.00	.53990673E-16	.00	-9.54	90.00
5000.00	.53303385E-16	.00	-3.19	90.00
10000.00	.53533171E-16	.00	-1.40	90.00

R= 3.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.98233910E-16	48.76	-.07	-.05
.20	.98191581E-16	48.77	-.10	-.07
.50	.98107645E-16	48.78	-.15	-.11
1.00	.98013187E-16	48.78	-.22	-.16
2.00	.97873446E-16	48.80	-.31	-.22
5.00	.97660648E-16	48.82	-.47	-.34
10.00	.97556878E-16	48.83	-.72	-.52
20.00	.97475994E-16	48.84	-1.27	-.91
50.00	.97473834E-16	48.83	-2.94	-2.11
100.00	.98019053E-16	48.76	-6.31	-4.43
200.00	.95299231E-16	49.29	-15.07	-10.51
500.00	.73441187E-16	52.68	-25.38	-19.59
1000.00	.57176190E-16	54.31	-18.21	-18.53
2000.00	.50613490E-16	52.37	-7.37	-12.44
5000.00	.49109218E-16	49.85	-1.53	-5.61
10000.00	.49082476E-16	49.13	-.43	-2.86

HOR. MAGN. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= 3.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.76684126E-16	74.44	.01	-.05
.20	.76658375E-16	74.44	.01	-.07
.50	.76607307E-16	74.42	.02	-.11
1.00	.76549828E-16	74.41	.03	-.16
2.00	.76464782E-16	74.39	.05	-.22
5.00	.76335267E-16	74.35	.07	-.34
10.00	.76272227E-16	74.34	.11	-.52
20.00	.76223275E-16	74.32	.19	-.91
50.00	.76210863E-16	74.32	.46	-2.11
100.00	.76555138E-16	74.34	1.44	-4.43
200.00	.75518884E-16	73.05	2.42	-10.51
500.00	.62985199E-16	68.01	-8.61	-19.59
1000.00	.50667531E-16	66.42	-19.05	-18.53
2000.00	.43071931E-16	68.54	-22.42	-12.44
5000.00	.39403616E-16	72.30	-16.45	-5.61
10000.00	.38673871E-16	73.69	-10.08	-2.86

R= 3.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.63211809E-16	.00	-.03	-.05
.20	.63197833E-16	.00	-.04	-.07
.50	.63170120E-16	.00	-.06	-.11
1.00	.63138904E-16	.00	-.09	-.16
2.00	.63092695E-16	.00	-.13	-.22
5.00	.63022288E-16	.00	-.20	-.34
10.00	.62988140E-16	.00	-.31	-.52
20.00	.62961874E-16	.00	-.55	-.91
50.00	.62940999E-16	.00	-1.26	-2.11
100.00	.63144006E-16	.00	-2.51	-4.43
200.00	.63353620E-16	.00	-6.05	-10.51
500.00	.57042953E-16	.00	-15.08	-19.59
1000.00	.47076960E-16	.00	-18.75	-18.53
2000.00	.38754668E-16	.00	-16.48	-12.44
5000.00	.33512830E-16	.00	-9.46	-5.61
10000.00	.32232863E-16	.00	-5.29	-2.86

R= 5.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.28430906E-16	.00	-.02	90.00
.20	.28425806E-16	.00	-.03	90.00
.50	.28415682E-16	.00	-.05	90.00
1.00	.28404275E-16	.00	-.07	90.00
2.00	.28387410E-16	.00	-.11	90.00
5.00	.28361691E-16	.00	-.16	90.00
10.00	.28348632E-16	.00	-.25	90.00
20.00	.28337599E-16	.00	-.44	90.00
50.00	.28322130E-16	.00	-1.00	90.00
100.00	.28368925E-16	.00	-1.82	90.00
200.00	.29009938E-16	.00	-4.08	90.00
500.00	.27565071E-16	.00	-16.63	90.00
1000.00	.21293521E-16	.00	-23.89	90.00
2000.00	.16182244E-16	.00	-19.34	90.00
5000.00	.14223100E-16	.00	-8.07	90.00
10000.00	.14117490E-16	.00	-3.60	90.00

HOR. MAGN. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= 5.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.25750895E-16	47.02	-.02	-.02
.20	.25746485E-16	47.03	-.03	-.02
.50	.25737729E-16	47.03	-.06	-.04
1.00	.25727866E-16	47.03	-.08	-.06
2.00	.25713280E-16	47.04	-.12	-.09
5.00	.25691039E-16	47.04	-.18	-.13
10.00	.25679776E-16	47.05	-.28	-.20
20.00	.25670322E-16	47.05	-.49	-.36
50.00	.25657112E-16	47.06	-1.11	-.83
100.00	.25696420E-16	47.03	-2.01	-1.51
200.00	.26244971E-16	46.79	-4.57	-3.29
500.00	.25082135E-16	47.69	-18.65	-13.45
1000.00	.19705184E-16	50.46	-26.16	-20.65
2000.00	.15116138E-16	52.01	-19.32	-19.36
5000.00	.13085843E-16	49.60	-6.21	-10.80
10000.00	.12865548E-16	48.05	-2.19	-5.80

R= 5.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.19305262E-16	77.42	.01	-.02
.20	.19302634E-16	77.41	.01	-.02
.50	.19297419E-16	77.41	.02	-.04
1.00	.19291545E-16	77.40	.03	-.06
2.00	.19282853E-16	77.39	.04	-.09
5.00	.19269604E-16	77.38	.06	-.13
10.00	.19262998E-16	77.37	.09	-.20
20.00	.19257657E-16	77.37	.16	-.36
50.00	.19250352E-16	77.35	.35	-.83
100.00	.19269830E-16	77.39	.57	-1.51
200.00	.19576584E-16	77.76	2.27	-3.29
500.00	.19174840E-16	75.33	4.88	-13.45
1000.00	.16064086E-16	71.09	-7.26	-20.65
2000.00	.12718599E-16	69.50	-19.45	-19.36
5000.00	.10446273E-16	72.56	-23.32	-10.80
10000.00	.98974660E-17	75.21	-18.16	-5.80

R= 5.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.15082620E-16	.00	-.01	-.02
.20	.15081338E-16	.00	-.01	-.02
.50	.15078800E-16	.00	-.02	-.04
1.00	.15075940E-16	.00	-.03	-.06
2.00	.15071701E-16	.00	-.05	-.09
5.00	.15065248E-16	.00	-.07	-.13
10.00	.15062177E-16	.00	-.12	-.20
20.00	.15059990E-16	.00	-.21	-.36
50.00	.15057235E-16	.00	-.49	-.83
100.00	.15061091E-16	.00	-.92	-1.51
200.00	.15181063E-16	.00	-1.77	-3.29
500.00	.15393339E-16	.00	-7.76	-13.45
1000.00	.13890110E-16	.00	-15.67	-20.65
2000.00	.11331167E-16	.00	-19.40	-19.36
5000.00	.88355698E-17	.00	-15.21	-10.80
10000.00	.80111539E-17	.00	-9.67	-5.80

HOR. ELEC. DIPOLE

THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10519036E-18	.00	-.79	90.00
.20	.26147492E-19	.00	-1.13	90.00
.50	.41363776E-20	.00	-1.79	90.00
1.00	.10209607E-20	.00	-2.56	90.00
2.00	.25045230E-21	.00	-3.63	90.00
5.00	.38941119E-22	.00	-5.48	90.00
10.00	.96148751E-23	.00	-8.50	90.00
20.00	.23896404E-23	.00	-15.14	90.00
50.00	.38491292E-24	.00	-34.34	90.00
100.00	.10198621E-24	.00	-59.86	90.00
200.00	.30230378E-25	.00	89.06	90.00
500.00	.67189915E-26	.00	54.25	90.00
1000.00	.20822096E-26	.00	36.42	90.00
2000.00	.60923654E-27	.00	23.81	90.00
5000.00	.10915145E-27	.00	13.41	90.00
10000.00	.28864453E-28	.00	9.49	90.00

R= .20 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10572226E-18	.49	-.79	.00
.20	.26280462E-19	.49	-1.12	.00
.50	.41576482E-20	.50	-1.79	.00
1.00	.10262761E-20	.51	-2.55	.00
2.00	.25178004E-21	.52	-3.61	.00
5.00	.39153070E-22	.53	-5.45	.00
10.00	.96675307E-23	.54	-8.45	.00
20.00	.24024931E-23	.54	-15.06	.00
50.00	.38667597E-24	.54	-34.16	.00
100.00	.10225641E-24	.51	-59.60	.00
200.00	.30229382E-25	.43	89.31	.00
500.00	.67067761E-26	.31	54.40	.00
1000.00	.20779834E-26	.25	36.50	.00
2000.00	.60803346E-27	.21	23.86	.00
5000.00	.10894665E-27	.19	13.44	.00
10000.00	.28812524E-28	.18	9.51	.00

R= .20 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10677821E-18	.49	-.78	.00
.20	.26544425E-19	.49	-1.11	.00
.50	.41998701E-20	.49	-1.77	.00
1.00	.10368262E-20	.50	-2.52	.00
2.00	.25441497E-21	.51	-3.57	.00
5.00	.39573597E-22	.52	-5.39	.00
10.00	.97719997E-23	.53	-8.36	.00
20.00	.24279968E-23	.53	-14.90	.00
50.00	.39017842E-24	.53	-33.81	.00
100.00	.10279474E-24	.50	-59.09	.00
200.00	.30227388E-25	.43	89.81	.00
500.00	.66822766E-26	.31	54.69	.00
1000.00	.20695042E-26	.25	36.68	.00
2000.00	.60561993E-27	.21	23.96	.00
5000.00	.10853583E-27	.19	13.49	.00
10000.00	.28708370E-28	.18	9.54	.00

HOR. ELEC. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH
R= .20 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10730230E-18	.00	-.78	.00
.20	.26675428E-19	.00	-1.10	.00
.50	.42208226E-20	.00	-1.76	.00
1.00	.10420613E-20	.00	-2.51	.00
2.00	.25572225E-21	.00	-3.55	.00
5.00	.39782197E-22	.00	-5.36	.00
10.00	.98238177E-23	.00	-8.32	.00
20.00	.24406487E-23	.00	-14.82	.00
50.00	.39191795E-24	.00	-33.64	.00
100.00	.10306285E-24	.00	-58.84	.00
200.00	.30226390E-25	.00	-89.93	.00
500.00	.66699931E-26	.00	54.84	.00
1000.00	.20652517E-26	.00	36.76	.00
2000.00	.60440957E-27	.00	24.01	.00
5000.00	.10832984E-27	.00	13.52	.00
10000.00	.28656153E-28	.00	9.56	.00

R= 3.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.16641300E-19	.00	-.17	90.00
.20	.41552257E-20	.00	-.24	90.00
.50	.66322061E-21	.00	-.38	90.00
1.00	.16535083E-21	.00	-.54	90.00
2.00	.41170014E-22	.00	-.77	90.00
5.00	.65465900E-23	.00	-1.15	90.00
10.00	.16321006E-23	.00	-1.78	90.00
20.00	.40749094E-24	.00	-3.16	90.00
50.00	.65416111E-25	.00	-7.27	90.00
100.00	.16849856E-25	.00	-13.54	90.00
200.00	.48704637E-26	.00	-26.48	90.00
500.00	.12079730E-26	.00	-64.63	90.00
1000.00	.44340330E-27	.00	81.57	90.00
2000.00	.15283588E-27	.00	54.97	90.00
5000.00	.32593614E-28	.00	31.84	90.00
10000.00	.93306806E-29	.00	20.94	90.00

R= 3.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.30047310E-19	31.33	-.11	.00
.20	.75074672E-20	31.35	-.15	.00
.50	.11998126E-20	31.39	-.24	.00
1.00	.29956437E-21	31.44	-.35	.00
2.00	.74747509E-22	31.51	-.49	.00
5.00	.11924771E-22	31.61	-.74	.00
10.00	.29771830E-23	31.66	-1.14	.00
20.00	.74371286E-24	31.68	-2.03	.00
50.00	.11905002E-24	31.67	-4.68	.00
100.00	.30085504E-25	31.29	-8.82	.00
200.00	.79836373E-26	29.29	-18.17	.00
500.00	.15341566E-26	24.04	-51.17	.00
1000.00	.46630689E-27	19.58	-86.70	.00
2000.00	.14641342E-27	15.47	62.49	.00
5000.00	.30242362E-28	11.92	35.53	.00
10000.00	.86367399E-29	10.42	23.12	.00

HOR. ELEC. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= 3.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.46418297E-19	19.67	-.06	.00
.20	.11599761E-19	19.68	-.09	.00
.50	.18544354E-20	19.69	-.14	.00
1.00	.46317898E-21	19.71	-.20	.00
2.00	.11563579E-21	19.74	-.29	.00
5.00	.18463072E-22	19.78	-.43	.00
10.00	.46112218E-23	19.80	-.67	.00
20.00	.11520543E-23	19.82	-1.18	.00
50.00	.18428297E-24	19.82	-2.73	.00
100.00	.46341975E-25	19.70	-5.18	.00
200.00	.11990522E-25	19.01	-11.04	.00
500.00	.20353170E-26	17.88	-34.30	.00
1000.00	.50903182E-27	17.87	-64.87	.00
2000.00	.13263878E-27	17.13	80.90	.00
5000.00	.24881989E-28	14.54	45.56	.00
10000.00	.70467425E-29	12.81	29.04	.00

R= 3.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.52731083E-19	.00	-.05	.00
.20	.13177657E-19	.00	-.07	.00
.50	.21068035E-20	.00	-.12	.00
1.00	.52624402E-21	.00	-.17	.00
2.00	.13139203E-21	.00	-.24	.00
5.00	.20981600E-22	.00	-.36	.00
10.00	.52405385E-23	.00	-.55	.00
20.00	.13093089E-23	.00	-.98	.00
50.00	.20941317E-24	.00	-2.26	.00
100.00	.52619384E-25	.00	-4.30	.00
200.00	.13556907E-25	.00	-9.21	.00
500.00	.22443161E-26	.00	-29.10	.00
1000.00	.52910211E-27	.00	-55.99	.00
2000.00	.12518436E-27	.00	-88.85	.00
5000.00	.21711054E-28	.00	52.38	.00
10000.00	.60982150E-29	.00	33.15	.00

R= 5.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.70523036E-20	.00	-.09	90.00
.20	.17618512E-20	.00	-.13	90.00
.50	.28151023E-21	.00	-.21	90.00
1.00	.70268850E-22	.00	-.30	90.00
2.00	.17527016E-22	.00	-.43	90.00
5.00	.27945659E-23	.00	-.65	90.00
10.00	.69752523E-24	.00	-1.00	90.00
20.00	.17422719E-24	.00	-1.77	90.00
50.00	.27894211E-25	.00	-4.12	90.00
100.00	.70272725E-26	.00	-7.82	90.00
200.00	.18512194E-26	.00	-13.75	90.00
500.00	.44861580E-27	.00	-34.90	90.00
1000.00	.18381820E-27	.00	-69.24	90.00
2000.00	.71385981E-28	.00	77.10	90.00
5000.00	.17243151E-28	.00	45.56	90.00
10000.00	.52599601E-29	.00	30.30	90.00

HOR. ELEC. DIPOLE
THE TOTAL E-FIELD ON THE SURFACE OF THE EARTH

R= 5.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.19011824E-19	41.26	-.04	.00
.20	.47520344E-20	41.27	-.06	.00
.50	.76003495E-21	41.29	-.10	.00
1.00	.18992689E-21	41.31	-.15	.00
2.00	.47451441E-22	41.34	-.21	.00
5.00	.75848703E-23	41.39	-.31	.00
10.00	.18953569E-23	41.41	-.49	.00
20.00	.47370181E-24	41.43	-.87	.00
50.00	.75783159E-25	41.43	-2.02	.00
100.00	.18968058E-25	41.37	-3.85	.00
200.00	.47995909E-26	40.77	-6.95	.00
500.00	.86585558E-27	35.39	-21.32	.00
1000.00	.25334155E-27	29.66	-51.33	.00
2000.00	.76351335E-28	24.23	-88.21	.00
5000.00	.16154232E-28	18.08	53.30	.00
10000.00	.48154565E-29	15.09	34.81	.00

R= 5.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.31382781E-19	23.54	-.02	.00
.20	.78445707E-20	23.55	-.03	.00
.50	.12547764E-20	23.55	-.05	.00
1.00	.31359417E-21	23.56	-.07	.00
2.00	.78361526E-22	23.57	-.10	.00
5.00	.12528832E-22	23.59	-.15	.00
10.00	.31311429E-23	23.60	-.24	.00
20.00	.78260483E-24	23.61	-.43	.00
50.00	.12519222E-24	23.61	-1.00	.00
100.00	.31314488E-25	23.60	-1.91	.00
200.00	.78901346E-26	23.40	-3.48	.00
500.00	.13588988E-26	21.65	-11.72	.00
1000.00	.35350758E-27	20.77	-31.33	.00
2000.00	.85420504E-28	21.52	-61.13	.00
5000.00	.13719508E-28	21.44	74.63	.00
10000.00	.37724644E-29	19.41	48.24	.00

R= 5.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.36008243E-19	.00	-.01	.00
.20	.90008342E-20	.00	-.02	.00
.50	.14397464E-20	.00	-.04	.00
1.00	.35982751E-21	.00	-.06	.00
2.00	.89916481E-22	.00	-.08	.00
5.00	.14376797E-22	.00	-.12	.00
10.00	.35930342E-23	.00	-.19	.00
20.00	.89805836E-24	.00	-.34	.00
50.00	.14365967E-24	.00	-.80	.00
100.00	.35930517E-25	.00	-1.52	.00
200.00	.90478341E-26	.00	-2.78	.00
500.00	.15475970E-26	.00	-9.54	.00
1000.00	.39415788E-27	.00	-25.85	.00
2000.00	.89611555E-28	.00	-50.94	.00
5000.00	.12323056E-28	.00	87.72	.00
10000.00	.31229670E-29	.00	58.20	.00

HOR. ELEC. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10471918E-18	90.00	90.00	89.89
.20	.52321018E-19	90.00	90.00	89.85
.50	.20897836E-19	90.00	90.00	89.77
1.00	.10431720E-19	90.00	90.00	89.68
2.00	.52032093E-20	90.00	90.00	89.56
5.00	.20735927E-20	90.00	90.00	89.36
10.00	.10343866E-20	90.00	90.00	89.02
20.00	.51505732E-21	90.00	90.00	88.29
50.00	.20218390E-21	90.00	90.00	86.46
100.00	.97448361E-22	90.00	90.00	84.74
200.00	.45974520E-22	90.00	90.00	83.68
500.00	.16959548E-22	90.00	90.00	84.36
1000.00	.81203171E-23	90.00	90.00	85.85
2000.00	.39658261E-23	90.00	90.00	87.42
5000.00	.15685850E-23	90.00	90.00	88.75
10000.00	.78147221E-24	90.00	90.00	89.27

R= .20 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10472460E-18	89.99	-45.77	89.90
.20	.52324840E-19	89.98	-45.89	89.86
.50	.20900244E-19	89.98	-46.21	89.78
1.00	.10433417E-19	89.97	-46.56	89.69
2.00	.52044196E-20	89.96	-47.79	89.57
5.00	.20742961E-20	89.95	-48.11	89.38
10.00	.10348182E-20	89.93	-42.22	89.05
20.00	.51535775E-21	89.90	-37.43	88.34
50.00	.20243492E-21	89.81	-43.77	86.55
100.00	.97660345E-22	89.72	-55.49	84.84
200.00	.46123973E-22	89.63	-67.77	83.78
500.00	.17029363E-22	89.57	-78.52	84.43
1000.00	.81611048E-23	89.49	-82.11	85.91
2000.00	.39861250E-23	89.49	86.91	87.42
5000.00	.15756046E-23	89.56	-89.26	88.76
10000.00	.78523398E-24	89.52	-85.54	89.30

R= .20 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10473544E-18	89.99	-45.77	89.90
.20	.52332487E-19	89.98	-45.89	89.86
.50	.20905059E-19	89.98	-46.21	89.79
1.00	.10436813E-19	89.97	-46.56	89.71
2.00	.52068398E-20	89.96	-47.79	89.60
5.00	.20757024E-20	89.95	-48.11	89.41
10.00	.10356809E-20	89.93	-42.22	89.10
20.00	.51595818E-21	89.90	-37.43	88.43
50.00	.20293605E-21	89.81	-43.77	86.71
100.00	.98082951E-22	89.72	-55.49	85.04
200.00	.46421445E-22	89.63	-67.77	83.98
500.00	.17168142E-22	89.58	-78.52	84.58
1000.00	.82420765E-23	89.50	-82.11	86.03
2000.00	.40264162E-23	89.50	86.91	87.41
5000.00	.15895508E-23	89.56	-89.26	88.78
10000.00	.79270394E-24	89.53	-85.54	89.35

HOR. ELEC. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= .20 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.10474088E-18	89.99	-45.77	89.91
.20	.52336316E-19	89.99	-45.89	89.87
.50	.20907469E-19	89.99	-46.21	89.80
1.00	.10438509E-19	89.99	-46.56	89.72
2.00	.52080499E-20	89.99	-47.79	89.61
5.00	.20764054E-20	89.99	-48.11	89.43
10.00	.10361122E-20	89.99	-42.22	89.13
20.00	.51625818E-21	89.99	-37.43	88.48
50.00	.20318616E-21	89.99	-43.77	86.80
100.00	.98293575E-22	89.99	-55.49	85.14
200.00	.46569472E-22	89.99	-67.77	84.08
500.00	.17237111E-22	89.99	-78.52	84.65
1000.00	.82822661E-23	89.99	-82.11	86.09
2000.00	.40464117E-23	89.99	86.91	87.41
5000.00	.15964784E-23	89.99	-89.26	88.79
10000.00	.79641278E-24	89.99	-85.54	89.37

R= 3.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.35121789E-20	90.00	90.00	89.89
.20	.17547954E-20	90.00	90.00	89.85
.50	.70089283E-21	90.00	90.00	89.77
1.00	.34986944E-21	90.00	90.00	89.67
2.00	.17450859E-21	90.00	90.00	89.54
5.00	.69544316E-22	90.00	90.00	89.32
10.00	.34707228E-22	90.00	90.00	88.96
20.00	.17323888E-22	90.00	90.00	88.16
50.00	.68998694E-23	90.00	90.00	85.76
100.00	.34260251E-23	90.00	90.00	81.84
200.00	.16727073E-23	90.00	90.00	73.83
500.00	.56778106E-24	90.00	90.00	54.04
1000.00	.21299562E-24	90.00	90.00	34.38
2000.00	.72140264E-25	90.00	90.00	12.08
5000.00	.17726057E-25	90.00	90.00	-22.53
10000.00	.73162791E-26	90.00	90.00	-48.18

R= 3.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.35164147E-20	89.83	-45.05	89.96
.20	.17577937E-20	89.76	-45.07	89.95
.50	.70279271E-21	89.62	-45.11	89.92
1.00	.35121583E-21	89.46	-45.10	89.89
2.00	.17547640E-21	89.24	-45.81	89.85
5.00	.70112862E-22	88.88	-45.48	89.78
10.00	.35040824E-22	88.49	-37.80	89.66
20.00	.17519636E-22	87.64	-26.95	89.40
50.00	.70196727E-23	84.91	-17.66	88.63
100.00	.35440476E-23	80.27	-16.53	87.45
200.00	.18504957E-23	71.67	-25.13	84.72
500.00	.78960144E-24	57.70	-49.30	74.83
1000.00	.38062516E-24	47.44	-65.75	65.84
2000.00	.17565940E-24	37.50	-76.72	60.86
5000.00	.64572584E-25	27.04	-84.40	63.41
10000.00	.31286216E-25	22.42	-87.16	70.14

HOR. ELEC. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= 3.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.35248712E-20	89.83	-45.05	-89.89
.20	.17637751E-20	89.76	-45.07	-89.85
.50	.70657725E-21	89.62	-45.11	-89.76
1.00	.35389324E-21	89.47	-45.10	-89.67
2.00	.17739618E-21	89.25	-45.81	-89.54
5.00	.71236354E-22	88.90	-45.48	-89.33
10.00	.35698673E-22	88.51	-37.80	-88.97
20.00	.17904717E-22	87.69	-26.95	-88.20
50.00	.72533457E-23	85.08	-17.66	-85.89
100.00	.37690218E-23	80.86	-16.53	-82.15
200.00	.21626612E-23	74.39	-25.13	-77.62
500.00	.11070955E-23	67.60	-49.30	-81.97
1000.00	.58642327E-24	63.96	-65.75	-89.20
2000.00	.28663608E-24	60.91	-76.72	86.54
5000.00	.10899737E-24	58.15	-84.40	85.86
10000.00	.53192345E-25	57.06	-87.16	86.91

R= 3.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.35290919E-20	89.99	-45.05	-89.82
.20	.17667583E-20	89.99	-45.07	-89.75
.50	.70846191E-21	89.99	-45.11	-89.61
1.00	.35522436E-21	89.99	-45.10	-89.45
2.00	.17834831E-21	89.99	-45.81	-89.24
5.00	.71791509E-22	89.99	-45.48	-88.89
10.00	.36023092E-22	89.99	-37.80	-88.31
20.00	.18094183E-22	89.99	-26.95	-87.04
50.00	.73674036E-23	89.99	-17.66	-83.29
100.00	.38766164E-23	89.99	-16.53	-77.50
200.00	.23029303E-23	89.99	-25.13	-70.97
500.00	.12356194E-23	89.99	-49.30	-75.86
1000.00	.66588336E-24	89.99	-65.75	-84.11
2000.00	.32834774E-24	89.99	-76.72	-89.41
5000.00	.12544254E-24	89.99	-84.40	88.43
10000.00	.61275809E-25	89.99	-87.16	88.52

R= 5.00 THETA= .DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.83775386E-21	90.00	90.00	89.89
.20	.41856833E-21	90.00	90.00	89.85
.50	.16718278E-21	90.00	90.00	89.77
1.00	.83453739E-22	90.00	90.00	89.67
2.00	.41625208E-22	90.00	90.00	89.54
5.00	.16588294E-22	90.00	90.00	89.32
10.00	.82788798E-23	90.00	90.00	88.95
20.00	.41328347E-23	90.00	90.00	88.15
50.00	.16470502E-23	90.00	90.00	85.74
100.00	.81938494E-24	90.00	90.00	81.90
200.00	.40910298E-24	90.00	90.00	74.55
500.00	.16398166E-24	90.00	90.00	51.68
1000.00	.78214797E-25	90.00	90.00	20.83
2000.00	.38044262E-25	90.00	90.00	-14.55
5000.00	.16271500E-25	90.00	90.00	-51.20
10000.00	.86616489E-26	90.00	90.00	-67.74

HOR. ELEC. DIPOLE
THE TOTAL H-FIELD ON THE SURFACE OF THE EARTH

R= 5.00 THETA= 30.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.83882051E-21	89.82	-44.65	89.97
.20	.41932617E-21	89.74	-44.77	89.95
.50	.16766472E-21	89.59	-44.88	89.93
1.00	.83795972E-22	89.43	-44.89	89.90
2.00	.41871633E-22	89.19	-45.59	89.87
5.00	.16733267E-22	88.81	-45.22	89.81
10.00	.83638259E-23	88.38	-37.44	89.71
20.00	.41823475E-23	87.46	-26.38	89.48
50.00	.16767525E-23	84.56	-16.69	88.81
100.00	.84538055E-24	79.93	-13.90	87.75
200.00	.43884500E-24	70.91	-13.56	86.07
500.00	.22046026E-24	51.00	-29.68	79.20
1000.00	.13114929E-24	38.36	-50.20	64.45
2000.00	.69619068E-25	27.79	-66.77	45.38
5000.00	.27837609E-25	16.39	-79.75	18.47
10000.00	.13817852E-25	10.70	-84.71	-4.71

R= 5.00 THETA= 60.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.84094998E-21	89.82	-44.65	-89.88
.20	.42083787E-21	89.74	-44.77	-89.83
.50	.16862449E-21	89.60	-44.88	-89.73
1.00	.84476306E-22	89.43	-44.89	-89.62
2.00	.42360188E-22	89.20	-45.59	-89.47
5.00	.17019514E-22	88.83	-45.22	-89.23
10.00	.85311824E-23	88.41	-37.44	-88.82
20.00	.42796558E-23	87.52	-26.38	-87.93
50.00	.17346327E-23	84.74	-16.69	-85.30
100.00	.89510988E-24	80.49	-13.90	-81.32
200.00	.49297505E-24	73.08	-13.56	-73.66
500.00	.30336154E-24	62.79	-29.68	-66.62
1000.00	.19840691E-24	58.78	-50.20	-76.05
2000.00	.10791528E-24	55.20	-66.77	-86.61
5000.00	.42370671E-25	50.92	-79.75	86.57
10000.00	.20560904E-25	48.67	-84.71	85.86

R= 5.00 THETA= 90.DEGREE

T SEC	ABS.FLD. STRENGTH	ANGLE DEGREE	PHASX DEGREE	PHASY DEGREE
.10	.84201268E-21	89.99	-44.65	-89.80
.20	.42159172E-21	89.99	-44.77	-89.72
.50	.16910233E-21	89.99	-44.88	-89.57
1.00	.84814425E-22	89.99	-44.89	-89.39
2.00	.42602367E-22	89.99	-45.59	-89.16
5.00	.17160849E-22	89.99	-45.22	-88.76
10.00	.86136412E-23	89.99	-37.44	-88.12
20.00	.43274895E-23	89.99	-26.38	-86.69
50.00	.17628604E-23	89.99	-16.69	-82.53
100.00	.91896601E-24	89.99	-13.90	-76.40
200.00	.51792293E-24	89.99	-13.56	-65.69
500.00	.33725506E-24	89.99	-29.68	-58.41
1000.00	.22460607E-24	89.99	-50.20	-69.43
2000.00	.12265870E-24	89.99	-66.77	-80.96
5000.00	.48015047E-25	89.99	-79.75	-89.07
10000.00	.23209043E-25	89.99	-84.71	89.03

APPENDIX XII

Apparent resistivity computed from dipole fields.

E/H (mks) in ohms

E/H (practical) in millivolt/km-γ

Apparent resistivity in ohm-m.

See front page of Appendix IX for meaning of other symbols.

(F(PHI), H(RHO)) V.M.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872198E-01	.15813792E+02	.50015204E+01
.20	.14051750E-01	.11182027E+02	.50015092E+01
.50	.88865453E-02	.70716878E+01	.50008768E+01
1.00	.62898435E-02	.50052983E+01	.50106022E+01
2.00	.44568997E-02	.35466880E+01	.50315984E+01
5.00	.26288287E-02	.20919553E+01	.43762770E+01
10.00	.18146804E-02	.14440767E+01	.41707150E+01
20.00	.14591646E-02	.11611663E+01	.53932288E+01
50.00	.12547658E-02	.99851087E-00	.99702396E+01
100.00	.10876604E-02	.86553262E-00	.14982934E+02
200.00	.84369735E-03	.67139300E-00	.18030742E+02
500.00	.47088651E-03	.37471957E-00	.14041476E+02
1000.00	.25996140E-03	.20687070E-00	.85590974E+01
2000.00	.13476211E-03	.10724028E-00	.46001912E+01
5000.00	.54583660E-04	.43436295E-01	.18867117E+01
10000.00	.27351318E-04	.21765487E-01	.94747284E-00

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19871552E-01	.15813278E+02	.50011952E+01
.20	.14051628E-01	.11181930E+02	.50014224E+01
.50	.88863510E-02	.70715332E+01	.50006582E+01
1.00	.62897474E-02	.50052218E+01	.50104490E+01
2.00	.44583635E-02	.35478528E+01	.50349036E+01
5.00	.26253387E-02	.20891781E+01	.43646651E+01
10.00	.17819237E-02	.14180098E+01	.40215036E+01
20.00	.13894137E-02	.11056603E+01	.48899388E+01
50.00	.11706091E-02	.93154109E-00	.86776880E+01
100.00	.10911278E-02	.86829189E-00	.15078616E+02
200.00	.11692466E-02	.93045685E-00	.34629998E+02
500.00	.12198544E-02	.97072926E-00	.94231530E+02
1000.00	.11109181E-02	.88404051E-00	.15630552E+03
2000.00	.87246761E-03	.69428764E-00	.19281413E+03
5000.00	.47276875E-03	.37621741E-00	.14153954E+03
10000.00	.25470520E-03	.20268795E-00	.82164810E+02

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.20321455E-01	.16171300E+02	.52302188E+01
.20	.14273029E-01	.11358115E+02	.51602712E+01
.50	.89708763E-02	.71387963E+01	.50962413E+01
1.00	.63299971E-02	.50372515E+01	.50747806E+01
2.00	.44774076E-02	.35630076E+01	.50780092E+01
5.00	.26319200E-02	.20944153E+01	.43865754E+01
10.00	.17847651E-02	.14202709E+01	.40343388E+01
20.00	.13932454E-02	.11087094E+01	.49169460E+01
50.00	.11938998E-02	.95007524E-00	.90264296E+01
100.00	.10768971E-02	.85696746E-00	.14687865E+02
200.00	.95684748E-03	.76143501E-00	.23191331E+02
500.00	.11891799E-02	.94631927E-00	.89552016E+02
1000.00	.12214324E-02	.97198499E-00	.18895096E+03
2000.00	.11437025E-02	.91012950E-00	.33133428E+03
5000.00	.87581131E-03	.69694847E-00	.48573717E+03
10000.00	.57777718E-03	.45978046E-00	.42279614E+03

(EX,HY) H.M.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= ALL ANGLES

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19974218E-01	.15894977E+02	.50530058E+01
.20	.14103381E-01	.11223114E+02	.50383316E+01
.50	.89060986E-02	.70872479E+01	.50229083E+01
1.00	.62989399E-02	.50125369E+01	.50251052E+01
2.00	.44610022E-02	.35499526E+01	.50408652E+01
5.00	.26332641E-02	.20954849E+01	.43910570E+01
10.00	.18293206E-02	.14557270E+01	.42382822E+01
20.00	.14786975E-02	.11767100E+01	.55385856E+01
50.00	.12510402E-02	.99554613E-00	.99111210E+01
100.00	.10411302E-02	.82850506E-00	.13728413E+02
200.00	.75560167E-03	.60128868E-00	.14461923E+02
500.00	.36340601E-03	.28918930E-00	.83630451E+01
1000.00	.21321487E-03	.16967100E-00	.57576496E+01
2000.00	.10575047E-03	.84153547E-01	.28327278E+01
5000.00	.36356557E-04	.28931628E-01	.83703910E-00
10000.00	.19536330E-04	.15546517E-01	.48338838E-00

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA=ALL ANGLES

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872784E-01	.15814259E+02	.50018158E+01
.20	.14052562E-01	.11182673E+02	.50020872E+01
.50	.88867401E-02	.70718428E+01	.50010961E+01
1.00	.62900096E-02	.50054304E+01	.50108666E+01
2.00	.44583684E-02	.35478567E+01	.50349148E+01
5.00	.26254304E-02	.20892511E+01	.43649702E+01
10.00	.17836614E-02	.14193926E+01	.40293508E+01
20.00	.13954233E-02	.11104425E+01	.49323300E+01
50.00	.12034732E-02	.95769351E-00	.91717686E+01
100.00	.11526730E-02	.91726800E-00	.16827612E+02
200.00	.11433236E-02	.90982798E-00	.33111478E+02
500.00	.10253431E-02	.81594209E-00	.66576149E+02
1000.00	.78699372E-03	.62626968E-00	.78442742E+02
2000.00	.49351580E-03	.39272738E-00	.61693920E+02
5000.00	.21750783E-03	.17308723E-00	.29959189E+02
10000.00	.11061797E-03	.88026981E-01	.15497499E+02

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA=ALL ANGLES

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19752933E-01	.15718884E+02	.49416662E+01
.20	.13992609E-01	.11134964E+02	.49594968E+01
.50	.88634690E-02	.70533243E+01	.49749384E+01
1.00	.62792091E-02	.49968357E+01	.49936734E+01
2.00	.44532834E-02	.35438102E+01	.50234364E+01
5.00	.26236291E-02	.20878176E+01	.43589823E+01
10.00	.17831445E-02	.14189813E+01	.40270158E+01
20.00	.13956674E-02	.11106368E+01	.49340564E+01
50.00	.12005297E-02	.95535115E-00	.91269582E+01
100.00	.11158476E-02	.88796328E-00	.15769576E+02
200.00	.10646327E-02	.84720776E-00	.28710440E+02
500.00	.10615900E-02	.84478645E-00	.71366415E+02
1000.00	.96066186E-03	.76447039E-00	.11688300E+03
2000.00	.73386644E-03	.58399234E-00	.13641882E+03
5000.00	.38042379E-03	.30273162E-00	.91646434E+02
10000.00	.20142818E-03	.16029145E-00	.51386698E+02

(EY,HX) H.M.D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872110E-01	.15813722E+02	.50014760E+01
.20	.14051682E-01	.11181973E+02	.50014608E+01
.50	.88864873E-02	.70716417E+01	.50008116E+01
1.00	.62898220E-02	.50052812E+01	.50105680E+01
2.00	.44573592E-02	.35470536E+01	.50326356E+01
5.00	.26275070E-02	.20909036E+01	.43718779E+01
10.00	.18049204E-02	.14363100E+01	.41259728E+01
20.00	.14421785E-02	.11476491E+01	.52683940E+01
50.00	.12483643E-02	.99341671E-00	.98687676E+01
100.00	.11121785E-02	.88504350E-00	.15666040E+02
200.00	.91497773E-03	.72811612E-00	.21206123E+02
500.00	.57562614E-03	.45806871E-00	.20982694E+02
1000.00	.34505523E-03	.27458622E-00	.15079518E+02
2000.00	.18640716E-03	.14833810E-00	.88016768E+01
5000.00	.77294269E-04	.61508823E-01	.37833353E+01
10000.00	.39143893E-04	.31149719E-01	.19406100E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19865817E-01	.15808714E+02	.49983088E+01
.20	.14048479E-01	.11179424E+02	.49991808E+01
.50	.88853076E-02	.70707029E+01	.49994840E+01
1.00	.62893046E-02	.50048694E+01	.50097436E+01
2.00	.44573392E-02	.35470377E+01	.50325904E+01
5.00	.26266349E-02	.20902096E+01	.43689762E+01
10.00	.18003291E-02	.14326563E+01	.41050082E+01
20.00	.14360732E-02	.11427907E+01	.52238824E+01
50.00	.12519153E-02	.99624251E-00	.99249914E+01
100.00	.11297153E-02	.89899884E-00	.16163978E+02
200.00	.94641338E-03	.75313181E-00	.22688301E+02
500.00	.61364030E-03	.48831942E-00	.23845586E+02
1000.00	.37054758E-03	.29487239E-00	.17389945E+02
2000.00	.20330660E-03	.16178625E-00	.10469916E+02
5000.00	.85339697E-04	.67911171E-01	.46119271E+01
10000.00	.42996718E-04	.34215700E-01	.23414282E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19869191E-01	.15811399E+02	.50000068E+01
.20	.14050205E-01	.11180798E+02	.50004096E+01
.50	.88859443E-02	.70712096E+01	.50002005E+01
1.00	.62895992E-02	.50051039E+01	.50102130E+01
2.00	.44574472E-02	.35471237E+01	.50328348E+01
5.00	.26268381E-02	.20903713E+01	.43696522E+01
10.00	.18012029E-02	.14333517E+01	.41089942E+01
20.00	.14372075E-02	.11436934E+01	.52321384E+01
50.00	.12512012E-02	.99567425E-00	.99136721E+01
100.00	.11263855E-02	.89634907E-00	.16068833E+02
200.00	.94063450E-03	.74853313E-00	.22412074E+02
500.00	.60633070E-03	.48250262E-00	.23280878E+02
1000.00	.36575621E-03	.29105953E-00	.16943130E+02
2000.00	.20023649E-03	.15934313E-00	.10156093E+02
5000.00	.83794514E-04	.66681553E-01	.44464295E+01
10000.00	.42254598E-04	.33625140E-01	.22613000E+01

(EY,HX) H.M.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19875374E-01	.15816320E+02	.50031196E+01
.20	.14053319E-01	.11183276E+02	.50026264E+01
.50	.88871176E-02	.70721433E+01	.50015211E+01
1.00	.62901398E-02	.50055340E+01	.50110742E+01
2.00	.44576437E-02	.35472800E+01	.50332780E+01
5.00	.26272098E-02	.20906671E+01	.43708889E+01
10.00	.18028013E-02	.14346236E+01	.41162898E+01
20.00	.14393077E-02	.11453646E+01	.52474404E+01
50.00	.12499905E-02	.99471080E-00	.98944958E+01
100.00	.11203586E-02	.89155302E-00	.15897336E+02
200.00	.93003074E-03	.74009492E-00	.21909620E+02
500.00	.59290498E-03	.47181878E-00	.22261296E+02
1000.00	.35699477E-03	.28408740E-00	.16141130E+02
2000.00	.19463586E-03	.15488629E-00	.95959052E+01
5000.00	.80979028E-04	.64441061E-01	.41526503E+01
10000.00	.40902770E-04	.32549389E-01	.21189254E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19878212E-01	.15818578E+02	.50045482E+01
.20	.14054758E-01	.11184421E+02	.50036508E+01
.50	.88876541E-02	.70725702E+01	.50021249E+01
1.00	.62903883E-02	.50057318E+01	.50114702E+01
2.00	.44577374E-02	.35473546E+01	.50334900E+01
5.00	.26273807E-02	.20908031E+01	.43714576E+01
10.00	.18035346E-02	.14352072E+01	.41196394E+01
20.00	.14402816E-02	.11461396E+01	.52545440E+01
50.00	.12494777E-02	.99430273E-00	.98863792E+01
100.00	.11176248E-02	.88937753E-00	.15819848E+02
200.00	.92515595E-03	.73621569E-00	.21680542E+02
500.00	.58672616E-03	.46690183E-00	.21799732E+02
1000.00	.35297924E-03	.28089195E-00	.15780058E+02
2000.00	.19207483E-03	.15284829E-00	.93450400E+01
5000.00	.79692901E-04	.63417594E-01	.40217912E+01
10000.00	.40285418E-04	.32058116E-01	.20554456E+01

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872591E-01	.15814105E+02	.50017184E+01
.20	.14052316E-01	.11182477E+02	.50019116E+01
.50	.88868331E-02	.70719169E+01	.50012009E+01
1.00	.62900015E-02	.50054240E+01	.50108538E+01
2.00	.44583555E-02	.35478465E+01	.50348860E+01
5.00	.26254225E-02	.20892448E+01	.43649438E+01
10.00	.17836574E-02	.14193894E+01	.40293326E+01
20.00	.13953281E-02	.11103668E+01	.49316576E+01
50.00	.12050632E-02	.95895879E-00	.91960196E+01
100.00	.11661240E-02	.92797196E-00	.17222639E+02
200.00	.11752281E-02	.93521678E-00	.34985217E+02
500.00	.10524556E-02	.83751753E-00	.70143561E+02
1000.00	.75023908E-03	.59702127E-00	.71286880E+02
2000.00	.40086049E-03	.31899463E-00	.40703028E+02
5000.00	.14684532E-03	.11685579E-00	.13655276E+02
10000.00	.69266786E-04	.55120755E-01	.60765952E+01

(EY,HX) H.M.D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872462E-01	.15814002E+02	.50016532E+01
.20	.14052118E-01	.11182320E+02	.50017712E+01
.50	.88868584E-02	.70719370E+01	.50012293E+01
1.00	.62900039E-02	.50054259E+01	.50108576E+01
2.00	.44583400E-02	.35478341E+01	.50348508E+01
5.00	.26254189E-02	.20892419E+01	.43649317E+01
10.00	.17836533E-02	.14193862E+01	.40293144E+01
20.00	.13952645E-02	.11103162E+01	.49312084E+01
50.00	.12060921E-02	.95977757E-00	.92117298E+01
100.00	.11749576E-02	.93500152E-00	.17484557E+02
200.00	.11981779E-02	.95347965E-00	.36364938E+02
500.00	.10881482E-02	.86592080E-00	.74981883E+02
1000.00	.74550712E-03	.59325570E-00	.70390466E+02
2000.00	.34749411E-03	.27652702E-00	.30586877E+02
5000.00	.10299063E-03	.81957337E-01	.67170051E+01
10000.00	.42863225E-04	.34109470E-01	.23269118E+01

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19873360E-01	.15814717E+02	.50021054E+01
.20	.14053443E-01	.11183374E+02	.50027140E+01
.50	.88863644E-02	.70715439E+01	.50006733E+01
1.00	.62899162E-02	.50053561E+01	.50107180E+01
2.00	.44584620E-02	.35479312E+01	.50351264E+01
5.00	.26254439E-02	.20892618E+01	.43650149E+01
10.00	.17836869E-02	.14194129E+01	.40294660E+01
20.00	.13959024E-02	.11108238E+01	.49357180E+01
50.00	.11946567E-02	.95067757E-00	.90378784E+01
100.00	.10827406E-02	.86161757E-00	.14847697E+02
200.00	.10443857E-02	.83109571E-00	.27628803E+02
500.00	.11106971E-02	.88386464E-00	.78121670E+02
1000.00	.10481513E-02	.83409228E-00	.13914199E+03
2000.00	.87930590E-03	.69972938E-00	.19584848E+03
5000.00	.54558085E-03	.43415943E-00	.18849441E+03
10000.00	.31766356E-03	.25278862E-00	.12780417E+03

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872933E-01	.15814377E+02	.50018904E+01
.20	.14052717E-01	.11182797E+02	.50021980E+01
.50	.88865832E-02	.70717180E+01	.50009195E+01
1.00	.62899706E-02	.50053994E+01	.50108046E+01
2.00	.44583899E-02	.35478738E+01	.50349636E+01
5.00	.26254330E-02	.20892531E+01	.43649785E+01
10.00	.17836684E-02	.14193982E+01	.40293826E+01
20.00	.13955826E-02	.11105693E+01	.49334568E+01
50.00	.12006971E-02	.95548436E-00	.91295036E+01
100.00	.11297826E-02	.89905240E-00	.16165904E+02
200.00	.10982585E-02	.87396632E-00	.30552685E+02
500.00	.10284036E-02	.81837756E-00	.66974183E+02
1000.00	.87667009E-03	.69763187E-00	.97338046E+02
2000.00	.64329584E-03	.51191855E-00	.10482424E+03
5000.00	.33415393E-03	.26591124E-00	.70708788E+02
10000.00	.18027022E-03	.14345448E-00	.41158376E+02

(EY,HX) H.M.D.

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19688642E-01	.15667723E+02	.49095508E+01
.20	.13960652E-01	.11109534E+02	.49368700E+01
.50	.88512825E-02	.70436266E+01	.49612676E+01
1.00	.62733563E-02	.49921782E+01	.49843686E+01
2.00	.44504951E-02	.35415914E+01	.50171480E+01
5.00	.26226593E-02	.20870459E+01	.43557606E+01
10.00	.17828107E-02	.14187156E+01	.40255080E+01
20.00	.13955087E-02	.11105105E+01	.49329344E+01
50.00	.11998730E-02	.95482856E-00	.91169758E+01
100.00	.11140423E-02	.88652667E-00	.15718591E+02
200.00	.10742438E-02	.85485603E-00	.29231153E+02
500.00	.10981883E-02	.87391045E-00	.76371947E+02
1000.00	.99326114E-03	.79041208E-00	.12495025E+03
2000.00	.71486694E-03	.56887302E-00	.12944660E+03
5000.00	.31176129E-03	.24809174E-00	.61549511E+02
10000.00	.14901869E-03	.11858530E-00	.28124946E+02

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19648865E-01	.15636069E+02	.48897330E+01
.20	.13940861E-01	.11093784E+02	.49228816E+01
.50	.88437287E-02	.70376155E+01	.49528032E+01
1.00	.62697267E-02	.49892898E+01	.49786026E+01
2.00	.44487649E-02	.35402145E+01	.50132476E+01
5.00	.26220571E-02	.20865667E+01	.43537606E+01
10.00	.17826032E-02	.14185505E+01	.40245710E+01
20.00	.13954097E-02	.11104317E+01	.49322344E+01
50.00	.11994644E-02	.95450341E-00	.91107676E+01
100.00	.11129098E-02	.88562545E-00	.15686649E+02
200.00	.10800602E-02	.85948457E-00	.29548549E+02
500.00	.11228108E-02	.89350442E-00	.79835015E+02
1000.00	.10244972E-02	.81526894E-00	.13293269E+03
2000.00	.71404742E-03	.56822086E-00	.12914998E+03
5000.00	.27072862E-03	.21543898E-00	.46413954E+02
10000.00	.11714540E-03	.93221344E-01	.17380438E+02

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.20193020E-01	.16069094E+02	.51643156E+01
.20	.14210420E-01	.11308293E+02	.51150996E+01
.50	.89461385E-02	.71191106E+01	.50681736E+01
1.00	.63187967E-02	.50283385E+01	.50568376E+01
2.00	.44720792E-02	.35587674E+01	.50659300E+01
5.00	.26301388E-02	.20929979E+01	.43806402E+01
10.00	.17853665E-02	.14207495E+01	.40370582E+01
20.00	.13967102E-02	.11114666E+01	.49414320E+01
50.00	.12048893E-02	.95882041E-00	.91933658E+01
100.00	.11273299E-02	.89710060E-00	.16095790E+02
200.00	.99230752E-03	.78965321E-00	.24942088E+02
500.00	.93894178E-03	.74718610E-00	.55828707E+02
1000.00	.99928202E-03	.79520334E-00	.12646967E+03
2000.00	.94327836E-03	.75063704E-00	.22538239E+03
5000.00	.73121713E-03	.58188408E-00	.33858908E+03
10000.00	.50436626E-03	.40136190E-00	.32218274E+03

(FY,HX) H.M.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19874767E-01	.15815837E+02	.50028140E+01
.20	.14053069E-01	.11183077E+02	.50024484E+01
.50	.88864836E-02	.70716387E+01	.50008074E+01
1.00	.62902504E-02	.50056221E+01	.50112506E+01
2.00	.44585364E-02	.35479904E+01	.50352944E+01
5.00	.26254534E-02	.20892694E+01	.43650466E+01
10.00	.17837704E-02	.14194793E+01	.40298430E+01
20.00	.13959636E-02	.11108725E+01	.49361508E+01
50.00	.12017594E-02	.95632971E-00	.91456651E+01
100.00	.11191760E-02	.89061193E-00	.15863792E+02
200.00	.10457533E-02	.83218401E-00	.27701209E+02
500.00	.10049646E-02	.79972539E-00	.63956070E+02
1000.00	.94188361E-03	.74952714E-00	.11235819E+03
2000.00	.79346595E-03	.63142012E-00	.15947655E+03
5000.00	.50101468E-03	.39869480E-00	.15895754E+03
10000.00	.29654494E-03	.23598296E-00	.11137591E+03

(E(RHO),H(PHI)) V.E.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872038E-01	.15813665E+02	.50014400E+01
.20	.14051655E-01	.11181951E+02	.50014412E+01
.50	.88865434E-02	.70716863E+01	.50008747E+01
1.00	.62897518E-02	.50052253E+01	.50104560E+01
2.00	.44587270E-02	.35481421E+01	.50357248E+01
5.00	.26246036E-02	.20885931E+01	.43622211E+01
10.00	.17731298E-02	.14110118E+01	.39819086E+01
20.00	.13786479E-02	.10970931E+01	.48144532E+01
50.00	.12021233E-02	.95661930E-00	.91512049E+01
100.00	.11586643E-02	.92203572E-00	.17002997E+02
200.00	.11399932E-02	.90717774E-00	.32918858E+02
500.00	.11294460E-02	.89878454E-00	.80781365E+02
1000.00	.11261473E-02	.89615952E-00	.16062038E+03
2000.00	.11248990E-02	.89516615E-00	.32052898E+03
5000.00	.11243589E-02	.89473636E-00	.80055315E+03
10000.00	.11241986E-02	.89460879E-00	.16006498E+04

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19872040E-01	.15813666E+02	.50014406E+01
.20	.14051653E-01	.11181950E+02	.50014404E+01
.50	.88865400E-02	.70716836E+01	.50008709E+01
1.00	.62897873E-02	.50052535E+01	.50105126E+01
2.00	.44583076E-02	.35478083E+01	.50347776E+01
5.00	.26254123E-02	.20892367E+01	.43649100E+01
10.00	.17841109E-02	.14197503E+01	.40313818E+01
20.00	.13976418E-02	.11122080E+01	.49480264E+01
50.00	.12046588E-02	.95863698E-00	.91898486E+01
100.00	.11117212E-02	.88467959E-00	.15653160E+02
200.00	.10144422E-02	.80726743E-00	.26067228E+02
500.00	.89995240E-03	.71615934E-00	.51288420E+02
1000.00	.84330336E-03	.67107947E-00	.90069532E+02
2000.00	.81223115E-03	.64635299E-00	.16710888E+03
5000.00	.79532578E-03	.63290013E-00	.40056257E+03
10000.00	.79104254E-03	.62949163E-00	.79251942E+03

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.19871657E-01	.15813362E+02	.50012484E+01
.20	.14051384E-01	.11181736E+02	.50012488E+01
.50	.88863713E-02	.70715494E+01	.50006811E+01
1.00	.62896664E-02	.50051573E+01	.50103200E+01
2.00	.44582242E-02	.35477420E+01	.50345892E+01
5.00	.26253667E-02	.20892004E+01	.43647583E+01
10.00	.17840040E-02	.14196652E+01	.40308986E+01
20.00	.13969962E-02	.11116942E+01	.49434560E+01
50.00	.12059016E-02	.95962597E-00	.92088200E+01
100.00	.11316344E-02	.90052601E-00	.16218942E+02
200.00	.10485663E-02	.83442252E-00	.27850438E+02
500.00	.88857413E-03	.70710480E-00	.49999720E+02
1000.00	.76508058E-03	.60883176E-00	.74135222E+02
2000.00	.67577280E-03	.53776289E-00	.11567557E+03
5000.00	.61671216E-03	.49076393E-00	.24084923E+03
10000.00	.59998906E-03	.47745611E-00	.45592868E+03

(EX,HY) H.E.D.

R = .00E-99 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.97502711E-00	.77590190E+03	.12040475E+05
.20	.48500584E-00	.38595537E+03	.59584620E+04
.50	.19202806E-00	.15281107E+03	.23351223E+04
1.00	.94914800E-01	.75530796E+02	.11409802E+04
2.00	.46654136E-01	.37126181E+02	.55134132E+03
5.00	.18186768E-01	.14472570E+02	.20945528E+03
10.00	.89982389E-02	.71605708E+01	.10254755E+03
20.00	.44893998E-02	.35725507E+01	.51052476E+02
50.00	.18403166E-02	.14644774E+01	.21446941E+02
100.00	.10115134E-02	.80493676E-00	.12958464E+02
200.00	.63508330E-03	.50538322E-00	.10216488E+02
500.00	.38368808E-03	.30532926E-00	.93225957E+01
1000.00	.24462889E-03	.19466948E-00	.75792412E+01
2000.00	.14234462E-03	.11327425E-00	.51324224E+01
5000.00	.67021674E-04	.53334152E-01	.28445318E+01
10000.00	.36858352E-04	.29330944E-01	.17206086E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.10044994E+01	.79935520E+03	.12779375E+05
.20	.49975121E-00	.39768936E+03	.63262732E+04
.50	.19793329E-00	.15751030E+03	.24809495E+04
1.00	.97870782E-01	.77883091E+02	.12131552E+04
2.00	.48134195E-01	.38303974E+02	.58687776E+03
5.00	.18779540E-01	.14944283E+02	.22333159E+03
10.00	.92952424E-02	.73969186E+01	.10942881E+03
20.00	.46395621E-02	.36920461E+01	.54524816E+02
50.00	.19037762E-02	.15149769E+01	.22951550E+02
100.00	.10465668E-02	.83283137E-00	.13872162E+02
200.00	.65754637E-03	.52325876E-00	.10951989E+02
500.00	.39617748E-03	.31526801E-00	.99393918E+01
1000.00	.25641974E-03	.20405234E-00	.83274714E+01
2000.00	.15362159E-03	.12224817E-00	.59778460E+01
5000.00	.69585934E-04	.55374725E-01	.30663602E+01
10000.00	.36935995E-04	.29392730E-01	.17278652E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.10094887E+01	.80332556E+03	.12906639E+05
.20	.50223694E-00	.39966745E+03	.63893628E+04
.50	.19892051E-00	.15829591E+03	.25057595E+04
1.00	.98360431E-01	.78272741E+02	.12253244E+04
2.00	.48376132E-01	.38496501E+02	.59279224E+03
5.00	.18874534E-01	.15019876E+02	.22559668E+03
10.00	.93418368E-02	.74339973E+01	.11052863E+03
20.00	.46615926E-02	.37095774E+01	.55043856E+02
50.00	.19100497E-02	.15199692E+01	.23103064E+02
100.00	.10470323E-02	.83320180E-00	.13884505E+02
200.00	.65538860E-03	.52154166E-00	.10880228E+02
500.00	.39384084E-03	.31340857E-00	.98224932E+01
1000.00	.25462770E-03	.20262628E-00	.82114818E+01
2000.00	.15254224E-03	.12138925E-00	.58941400E+01
5000.00	.69147577E-04	.55025892E-01	.30278488E+01
10000.00	.36693985E-04	.29200145E-01	.17052969E+01

(EX,HY) H.E.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.10194666E+01	.81126572E+03	.13163041E+05
.20	.50720770E-00	.40362305E+03	.65164628E+04
.50	.20089447E-00	.15986673E+03	.25557371E+04
1.00	.99339319E-01	.79051716E+02	.12498348E+04
2.00	.48859719E-01	.38881328E+02	.60470308E+03
5.00	.19064350E-01	.15170927E+02	.23015703E+03
10.00	.94349297E-02	.75080783E+01	.11274248E+03
20.00	.47055998E-02	.37445972E+01	.56088032E+02
50.00	.19225928E-02	.15299507E+01	.23407491E+02
100.00	.10480096E-02	.83397951E-00	.13910436E+02
200.00	.65114570E-03	.51816527E-00	.10739810E+02
500.00	.38922997E-03	.30973936E-00	.95938471E+01
1000.00	.25109719E-03	.19981679E-00	.79853500E+01
2000.00	.15041622E-03	.11969742E-00	.57309888E+01
5000.00	.68282406E-04	.54337410E-01	.29525541E+01
10000.00	.36216785E-04	.28820401E-01	.16612310E+01

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.10244548E+01	.81523520E+03	.13292169E+05
.20	.50969250E-00	.40560039E+03	.65804672E+04
.50	.20188109E-00	.16065186E+03	.25809020E+04
1.00	.99828548E-01	.79441032E+02	.12621755E+04
2.00	.49101345E-01	.39073608E+02	.61069872E+03
5.00	.19159166E-01	.15246379E+02	.23245207E+03
10.00	.94814227E-02	.75450762E+01	.11385635E+03
20.00	.47275739E-02	.37620837E+01	.56613096E+02
50.00	.19288614E-02	.15349391E+01	.23560380E+02
100.00	.10485208E-02	.83438631E-00	.13924010E+02
200.00	.64906019E-03	.51650567E-00	.10671124E+02
500.00	.38695537E-03	.30792929E-00	.94820448E+01
1000.00	.24935828E-03	.19843301E-00	.78751318E+01
2000.00	.14936927E-03	.11886428E-00	.56514868E+01
5000.00	.67855506E-04	.53997694E-01	.29157510E+01
10000.00	.35981534E-04	.28633194E-01	.16397196E+01

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.47381696E+01	.37705154E+04	.28433572E+06
.20	.23679260E+01	.18843356E+04	.14202883E+06
.50	.94625109E-00	.75300267E+03	.56701302E+05
1.00	.47260726E-00	.37608890E+03	.28288572E+05
2.00	.23591968E-00	.18773891E+03	.14098359E+05
5.00	.94135514E-01	.74910659E+02	.56116068E+04
10.00	.47024804E-01	.37421149E+02	.28006848E+04
20.00	.23521909E-01	.18718140E+02	.14014751E+04
50.00	.94807751E-02	.75445609E+01	.56920399E+03
100.00	.49181939E-02	.39137742E+01	.30635256E+03
200.00	.29117248E-02	.23170769E+01	.21475382E+03
500.00	.21275330E-02	.16930369E+01	.28663739E+03
1000.00	.20817483E-02	.16566026E+01	.54886644E+03
2000.00	.21185934E-02	.16859230E+01	.11369346E+04
5000.00	.18387402E-02	.14632229E+01	.21410213E+04
10000.00	.12753314E-02	.10148764E+01	.20599482E+04

(EX,HY) H.E.D.

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.72982946E+01	.58077981E+04	.67461038E+06
.20	.36471174E+01	.29022837E+04	.33693003E+06
.50	.14572366E+01	.11596320E+04	.13447464E+06
1.00	.72771125E-00	.57909419E+03	.67070016E+05
2.00	.36318468E-00	.28901318E+03	.33411447E+05
5.00	.14486645E-00	.11528105E+03	.13289720E+05
10.00	.72342534E-01	.57568358E+02	.66282316E+04
20.00	.36151886E-01	.28768756E+02	.33105653E+04
50.00	.14490537E-01	.11531203E+02	.13296864E+04
100.00	.73596790E-02	.58566463E+01	.68600612E+03
200.00	.39634127E-02	.31539835E+01	.39790448E+03
500.00	.20989768E-02	.16703126E+01	.27899442E+03
1000.00	.15669871E-02	.12469687E+01	.31098618E+03
2000.00	.13194611E-02	.10499937E+01	.44099472E+03
5000.00	.10078602E-02	.80202964E-00	.64325154E+03
10000.00	.71178607E-03	.56642134E-00	.64166626E+03

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.12400116E+02	.98676985E+04	.19474295E+07
.20	.61924780E+01	.49278173E+04	.97133532E+06
.50	.24709872E+01	.19663491E+04	.38665288E+06
1.00	.12321186E+01	.98048880E+03	.19227166E+06
2.00	.61357215E-00	.48826519E+03	.95361160E+05
5.00	.24391851E-00	.19410418E+03	.37676433E+05
10.00	.12156735E-00	.96740220E+02	.18717340E+05
20.00	.60580018E-01	.48208045E+02	.92960624E+04
50.00	.23988703E-01	.19089603E+02	.36441294E+04
100.00	.11724063E-01	.93297126E+01	.17408707E+04
200.00	.54423892E-02	.43309156E+01	.75027320E+03
500.00	.18923202E-02	.15058605E+01	.22676158E+03
1000.00	.91943101E-03	.73165993E-00	.10706525E+03
2000.00	.50604564E-03	.40269831E-00	.64866372E+02
5000.00	.26011715E-03	.20699464E-00	.42846781E+02
10000.00	.15391563E-03	.12248216E-00	.30003760E+02

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.14941827E+02	.11890328E+05	.28275980E+07
.20	.74586644E+01	.59354164E+04	.14091667E+07
.50	.29737709E+01	.23664516E+04	.56000932E+06
1.00	.14814412E+01	.11788934E+04	.27795792E+06
2.00	.73671582E-00	.58625980E+03	.13748022E+06
5.00	.29225739E-00	.23257103E+03	.54089284E+05
10.00	.14547719E-00	.11576707E+03	.26804028E+05
20.00	.72360759E-01	.57582861E+02	.13263144E+05
50.00	.28424283E-01	.22619325E+02	.51163386E+04
100.00	.13573533E-01	.10801474E+02	.23334368E+04
200.00	.58868073E-02	.46845723E+01	.87780872E+03
500.00	.18163488E-02	.14454044E+01	.20891939E+03
1000.00	.79458677E-03	.63231204E-00	.79963704E+02
2000.00	.38125542E-03	.30339341E-00	.36819024E+02
5000.00	.17307568E-03	.13772925E-00	.18969346E+02
10000.00	.99520760E-04	.79196102E-01	.12544045E+02

(EX,HY) H.E.D.

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= .00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.84181094E+01	.66989184E+04	.89751016E+06
.20	.42092322E+01	.33496004E+04	.44879292E+06
.50	.16838470E+01	.13399628E+04	.17955003E+06
1.00	.84200959E-00	.67004992E+03	.89793380E+05
2.00	.42106733E-00	.33507472E+03	.44910028E+05
5.00	.16846613E-00	.13406108E+03	.17972373E+05
10.00	.84253576E-01	.67046863E+02	.89905636E+04
20.00	.42156825E-01	.33547334E+02	.45016944E+04
50.00	.16935859E-01	.13477128E+02	.18163298E+04
100.00	.85762774E-02	.68247845E+01	.93155366E+03
200.00	.45250694E-02	.36009357E+01	.51866952E+03
500.00	.27357679E-02	.21770549E+01	.47395680E+03
1000.00	.23501716E-02	.18702071E+01	.69953492E+03
2000.00	.18763928E-02	.14931859E+01	.89184164E+03
5000.00	.10597148E-02	.84329422E-00	.71114514E+03
10000.00	.60727007E-03	.48325015E-00	.46706142E+03

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 30.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.17037431E+02	.13557956E+05	.36763634E+07
.20	.85175418E+01	.67780442E+04	.18376753E+07
.50	.34060973E+01	.27104860E+04	.73467344E+06
1.00	.17025300E+01	.13548303E+04	.36711302E+06
2.00	.85088025E-00	.67710897E+03	.18339062E+06
5.00	.34011844E-00	.27065765E+03	.73255564E+05
10.00	.17001016E-00	.13528978E+03	.36606650E+05
20.00	.85001525E-01	.67642062E+02	.18301794E+05
50.00	.34035969E-01	.27084963E+02	.73359522E+04
100.00	.17099589E-01	.13607420E+02	.37032376E+04
200.00	.87638267E-02	.69740315E+01	.19454846E+04
500.00	.41190517E-02	.32778371E+01	.10744216E+04
1000.00	.27046392E-02	.21522834E+01	.92646476E+03
2000.00	.21441881E-02	.17062906E+01	.11645710E+04
5000.00	.19546481E-02	.15554595E+01	.24194543E+04
10000.00	.18116059E-02	.14416301E+01	.41565946E+04

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA= 60.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.34210590E+02	.27223922E+05	.14822839E+08
.20	.17087713E+02	.13597970E+05	.73961916E+07
.50	.68211610E+01	.54281073E+04	.29464349E+07
1.00	.34027487E+01	.27078213E+04	.14664592E+07
2.00	.16956016E+01	.13493168E+04	.72826232E+06
5.00	.67473167E-00	.53693439E+03	.28829854E+06
10.00	.33644103E-00	.26773126E+03	.14336006E+06
20.00	.16771365E-00	.13346228E+03	.71248720E+05
50.00	.66406678E-01	.52844754E+02	.27925680E+05
100.00	.32503413E-01	.25865393E+02	.13380371E+05
200.00	.15352425E-01	.12217071E+02	.59702728E+04
500.00	.46812512E-02	.37252212E+01	.13877273E+04
1000.00	.19479755E-02	.15501496E+01	.48059276E+03
2000.00	.89667300E-03	.71354968E-00	.20366126E+03
5000.00	.38820698E-03	.30892529E-00	.95434835E+02
10000.00	.23043557E-03	.18337479E-00	.67252628E+02

(EX,HY) H.E.D.
R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06
THETA= 90.00

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.42764490E+02	.34030899E+05	.23162042E+08
.20	.21349646E+02	.16989508E+05	.11545735E+08
.50	.85140536E+01	.67752684E+04	.45904262E+07
1.00	.42425273E+01	.33760958E+04	.22796046E+07
2.00	.21105982E+01	.16795606E+04	.11283695E+07
5.00	.83776729E-00	.66667401E+03	.44445424E+06
10.00	.41713302E-00	.33194390E+03	.22037350E+06
20.00	.20752409E-00	.16514242E+03	.10908808E+06
50.00	.81492368E-01	.64849564E+02	.42054660E+05
100.00	.39098853E-01	.31113878E+02	.19361468E+05
200.00	.17469460E-01	.13901754E+02	.77303504E+04
500.00	.45888029E-02	.36516532E+01	.13334571E+04
1000.00	.17548852E-02	.13964932E+01	.39003866E+03
2000.00	.73057636E-03	.58137418E-00	.13519838E+03
5000.00	.25664989E-03	.20423549E-00	.41712135E+02
10000.00	.13455819E-03	.10707800E-00	.22931396E+02

C EY/HX H.E.D.

R = .20E-00 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA=ALL ANGLES

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.69588526E+02	.55376788E+05	.61331772E+08
.20	.24726524E+02	.19676742E+05	.15486967E+08
.50	.63091552E+01	.50206660E+04	.25207087E+07
1.00	.22478805E+01	.17888064E+04	.63996566E+06
2.00	.80280213E-00	.63884962E+03	.16325154E+06
5.00	.22151195E-00	.17627360E+03	.31072382E+05
10.00	.80796618E-01	.64295904E+02	.82679266E+04
20.00	.25739094E-01	.20482520E+02	.16781345E+04
50.00	.54644881E-02	.43485013E+01	.18909464E+03
100.00	.19264900E-02	.15330520E+01	.47004968E+02
200.00	.78116483E-03	.62163120E-00	.15457014E+02
500.00	.29113180E-03	.23167532E-00	.53673454E+01
1000.00	.12761100E-03	.10154960E-00	.20624642E+01
2000.00	.65521998E-04	.52140748E-01	.10874630E+01
5000.00	.30270829E-04	.24088760E-01	.58026836E-00
10000.00	.14080301E-04	.11204747E-01	.25109272E-00

R = .30E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA=ALL ANGLES

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.15111739E+04	.12025539E+07	.28922718E+11
.20	.53446304E+03	.42531216E+06	.72356172E+10
.50	.13532194E+03	.10768577E+06	.11596225E+10
1.00	.47836262E+02	.38066887E+05	.28981758E+09
2.00	.16892832E+02	.13442888E+05	.72284496E+08
5.00	.45983950E+01	.36592864E+04	.13390377E+08
10.00	.16936730E+01	.13477821E+04	.36330332E+07
20.00	.54160959E-00	.43099920E+03	.74304124E+06
50.00	.10049587E-00	.79972070E+02	.63955320E+05
100.00	.26110623E-01	.20778173E+02	.86346494E+04
200.00	.67155116E-02	.53440342E+01	.11423481E+04
500.00	.14818829E-02	.11792449E+01	.13906185E+03
1000.00	.60707014E-03	.48309105E-00	.46675392E+02
2000.00	.28035161E-03	.22309672E-00	.19908858E+02
5000.00	.10868827E-03	.86491374E-01	.74807578E+01
10000.00	.54034897E-04	.42999603E-01	.36979318E+01

R = .50E+01 S1= .2000E-00 S2= .2000E-02 D= .40E+04 E= .10E+06

THETA=ALL ANGLES

T	E/H(MKS)	E/H(PRAC)	APP.RESISTIVITY
.10	.47827508E+04	.38059920E+07	.28971150E+12
.20	.16881628E+04	.13433972E+07	.72188640E+11
.50	.42653602E+03	.33942657E+06	.11521040E+11
1.00	.15056950E+03	.11981940E+06	.28713378E+10
2.00	.53102194E+02	.42257382E+05	.71427452E+09
5.00	.14432182E+02	.11484765E+05	.13189983E+09
10.00	.53106720E+01	.42260984E+04	.35719816E+08
20.00	.16967850E+01	.13502586E+04	.72927932E+07
50.00	.31574851E-00	.25126467E+03	.63133934E+06
100.00	.84830226E-01	.67505747E+02	.91140518E+05
200.00	.21848416E-01	.17386416E+02	.12091498E+05
500.00	.36156546E-02	.28772464E+01	.82785468E+03
1000.00	.12192473E-02	.97024614E-00	.18827551E+03
2000.00	.50899338E-03	.40504405E-00	.65624272E+02
5000.00	.18779697E-03	.14944408E-00	.22333533E+02
10000.00	.92346634E-04	.73487114E-01	.10800712E+02